

# REFINING METALS ELECTRICALLY

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First Edition

PUBLISHED BY  
THE PENTON PUBLISHING Co.  
CLEVELAND, OHIO  
1922



## PREFACE

THE use of the electric furnace in the foundry is increasing rapidly. Problems which concern the metallurgy of electric furnace iron and steel, and those relating to general features of melting have been discussed at length. Much has been published in the technical and scientific press, but it is buried in the general mass of scientific literature. At present there is no book that deals with electric furnace practice as encountered exclusively in the foundry.

Therefore, Mr. Barton's work which deals not only with theory, but also stresses the practical operating side, will serve a useful purpose. This book summarizes and records as far as is possible the present state of the art and metallurgy of electric furnace products of the foundry.

The specialist may find in the following pages much that appears to him elementary, or the non-technical reader finds matter that appears too complex; but the author asks their indulgence because of his purpose to serve many readers.

This book is written for operators, managers and executives of electrically equipped foundries, from the standpoint of the practical man. The subject is presented in such a way that those unacquainted with electric furnace practice may study it and familiarize themselves with the points they should know if the installation of electrical units is contemplated. Determining whether to operate an acid or basic electric furnace; what points should be considered in choosing the right size of electric furnace; does economy in operation favor the unit ranging from 4 to 5 tons capacity or the smaller type, are questions of the utmost importance when considering the economy of a proposed electric furnace installation.

Maintenance and renewal items, types of linings, and

practical control features which assure economical operation with satisfactory metallurgical results are pertinent topics in the operating foundry.

To answer such questions as these the author has drawn upon his own experience and the reports of others for suggestions. Throughout this work whenever possible, credit has been assigned, and if in any instance it has been omitted, such oversight is unintentional.



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# REFINING METALS ELECTRICALLY

## I

### THE BEGINNING AND DEVELOPMENT OF THE ELECTRIC FURNACE

**P**ROBABLY the first to consider the practical exploitation of electrical energy was Davy who in 1810 used electric current to produce the necessary heat in his experiments on the electrolysis of aluminum oxide. Pepys in 1815 welded an iron wire by heating it electrically. His apparatus may be looked upon as the predecessor of our modern resistance furnace.

The first electrothermic furnace was that patented by Pichon in 1853. Such furnaces are used today with changes in design adapted from Stassano. Many other schemes were tried in the years immediately following Pichon's example, but they were doomed to failure because they were ahead of their times. William von Siemens in 1878 and 1879 obtained English patents on the design of the electric furnace which was the forerunner of the modern arc furnace. Siemen's furnace like the others was not a commercial success, because electricity was still too expensive.

Heroult successfully applied the electric furnace in the production of aluminum in 1887-88 and in 1894 he produced calcium carbide by the electric furnace. The iron and steel industries still failed to consider the project seriously until Stassano in 1898 took out a patent in several countries, claiming: "a method for the practical

steel and the increase in electric furnaces are evident from Tables I, II and III.

In making crucible steel, high grade selected scrap metal is placed in a graphite or clay crucible together with the necessary alloys to give a steel of the desired composition. This crucible is lowered into a pot furnace where the heat usually is obtained from a coke fire. The metal is melt-

Table II  
United States Production\*

	Total electric steel ingots and castings	Electric steel castings	Alloy steel castings
1913 .....	30,180	9,207	443
1916 .....	168,918	42,870	926
1918 .....	511,364	108,296	3,076
1920 .....	502,152	155,196	11,710
1921 .....	169,499	85,095	10,084
1922 .....	346,039	154,982	17,760

\*Annual Statistical Report American Iron and Steel institute.

Table III  
Electric Steel Furnaces in United States and Canada\*

Make of furnace	Jan. 1923	1922	1921	1920	1918
Heroult .....	181	179	177	170	146
Lectromelt .....	53	36	24	20	4
Snyder .....	53	54	54	49	35
Greaves-Etchell .....	28	28	25	18	12
Greene .....	27	23	18	11	1
Rennerfelt .....	18	18	17	18	13
Ludlum .....	14	13	13	12	6
Volta .....	13	13	8	....	....
Gronwall-Dixon .....	12	12	12	13	12
Booth .....	10	14	14	12	4
Girod .....	5	5	5	5	5
Vom Baur .....	5	6	5	4	0
Webb .....	2	2	2	2	2
Swindell .....	2	....	....	....	....
Miscellaneous .....	27	29	21	25	25
Total .....	456	438	399	363	269

\*Edwin F. Cone, *Iron Age*, Jan. 4, 1923.

ed, held a sufficient length of time to become thoroughly *killed* or freed from gas. The slag is then skimmed from the metal and it is poured either singly or several crucibles may be poured at one time by using a ladle. Crucible steel

from the quality standpoint cannot be excelled, but when it is considered that each pot holds only 80 or 100 pounds of metal it is easy to see that the cost of producing castings by this method is excessive.

### *Open-Hearth Tonnage Large*

The open-hearth furnace usually handles metal in amounts of over 15 or 20 tons at a heat. Under these conditions it is necessary to have a large tonnage of work always on the floor. As such a furnace will pour from three to five heats in 24 hours, and will not run intermittently in an economical manner, a heavy outlay in miscellaneous equipment is necessary to handle adequately such tonnage. Due to physical limitations there is a certain point above which the metal cannot be heated. This makes it difficult to pour small or intricate castings from open-hearth steel. Due to the sizes of individual heats it is impossible to accept orders for small tonnages of special analysis. However, the open-hearth furnace will turn out metal of acceptable quality at a low price, which gives it an advantage and forestalls competition, especially on heavy work where the margin of profit is low. Under ordinary conditions the electric furnace cannot compete with the open-hearth on a price basis.

Before the advent of the small electric furnace in the foundry business, the great majority of steel casting shops, especially the smaller ones, used the side blow converter for producing their metal. This equipment has several distinct advantages—it can turn out a large tonnage of metal in a short period of time, and can make extremely hot steel. Consequently the converter found great use where the castings were small in size, and as it could be operated intermittently was generally used for several blows on alternate days. Where the output was such that a greater quantity of metal was necessary, another converter could be installed for auxiliary service.

A 2 ton converter will blow a heat in approximately 20 minutes, giving an exceptional tonnage when necessary. For large heats several blows could be made in quick succession, the metal being held in the ladle. The writer knows of several instances where castings of 8 to 10 tons have been made from a 2 ton converter. Due to the small size of the heats, special metals could be made by alloying in the ladle or converter. Until the last few years, all of the manganese steel used was produced in this manner.

Consequently the converter offers keen competition to the electric furnace. However, in two main points—cost of molten metal, and quality—the electric furnace has amply demonstrated its superiority. These two points are greatly discussed. The makers of converters deny both of these contentions, but experience has shown them to be true. The best proof of the electric furnace favor is the ever increasing number of substitutions of electric furnaces for converters.

In *The Foundry* for Feb. 1, 1920, appears an interesting and important comparison of the two methods of melting as practiced at the Taylor-Wharton Iron & Steel Co., described by Messrs. John H. Hall and G. R. Hanks. They state the following conclusions:

“At our High Bridge plant we have a 3-ton, heroult electric furnace and a 3-ton, bottom-blow, bessemer converter working side by side. The electric furnace is operated on a basic bottom, which enables us to turn out a steel low in phosphorus and sulphur.

“During the war we had orders for castings for the army and navy, and to use the converter for this class of work we installed the Stoughton oil burning process in our cupolas, by which we were enabled to turn out steel sufficiently low in sulphur to meet the government's specifications and in many cases to get sulphur considerably below 0.06 per cent.

“We had always been able to meet the tensile tests for Classes 1, 2 and 3 army and navy A, B, C, and D steel with converter metal and after we had the oil

working successfully on the cupola we undertook to turn our army and navy work with the converter as well as with the electric furnace.

"We had not gone far with the more intricate castings before we were faced with the fact that the converter steel, even when the sulphur was around 0.05 per cent, was much more subject to hot cracks and tears than the electric steel and apparently it was not always true that the lower sulphur heats were any better in this respect than the high sulphur heats.

"To throw some light on this question we kept careful records on one of the cradle-band castings for a 240 millimeter howitzer. These castings were of Class 3 steel, but in our practice we poured them with steel running from 0.25 to 0.35 per cent carbon and we secured the desired tensile strength by heat treatment. The accompanying Table IV gives the analyses of a number of

Table IV

DATA ON ELECTRIC AND CONVERTER HEATS							
No. of cast	E or C	Carbon	Silicon	Manganese	Sulphur	Phosphorus	Remarks
1(A)	E	0.28	0.24	0.47	0.032	0.023	
4	E	0.44	0.51	1.40	0.014	0.040	
1	E	0.35	0.24	1.00	0.017	0.037	
3	C	0.30	.	0.87	0.047	0.049	2 cracked
2	C	0.29	0.47	1.11	0.046	0.050	1 cracked
2	C	0.27	0.56	0.84	0.065	0.041	1 cracked
1	C	0.30	.	1.13	0.055	0.043	1 cracked
2	C	0.26	.	0.98	0.057	0.049	1 cracked
1	C	0.27	0.38	1.00	0.070	0.045	
2	C	0.24	.	0.80	0.064	0.040	1 cracked
3	E	0.27	0.19	1.31	0.016	0.020	
2	C	0.28	0.56	1.07	0.065	0.043	
1	C	0.26	0.61	0.94	0.055	0.048	
5	E	0.31	0.33	1.00	0.015	0.027	
1	E	0.35	0.20	1.00	0.018	0.031	
3	E	0.30	0.28	0.93	0.014	0.020	
2	C	0.33	0.38	0.94	0.054	0.047	2 cracked
1(B)	C	0.28	.	0.88	0.038	0.045	1 cracked

converter and electric heats from which castings of this pattern were poured and shows clearly the large percentage of cracked and torn castings on the converter steel. An examination of this table will show that in the converter heats on which no castings were lost the sulphur was as high or higher than on the heats on which castings were rejected for hot cracks. It will also be noted that at least one of the electric furnace heats, 1 (A), is not low in sulphur and on this heat we lost no castings. In fact electric heat 1 (A) with 0.032 per cent sulphur is directly

comparable with converter heat number 1 (B) with 0.038 per cent sulphur, on which a casting cracked.

"In our efforts to overcome the hot tears in the foundry we used all of the *stunts* that could be worked out with any reasonable theory behind them, and some of them were as follows: The castings were made both in green and dry sand; they were taken out of the molds hot; were allowed to cool over night, etc. Some of these same molds were relieved to allow free shrinkage by destroying the sand grip, while others merely had the cope lifted and were allowed to remain until cold. During our experiments we determined that the castings poured from electric steel could be handled in any manner that time and equipment would allow, and our results produced few rejections, whereas with castings poured from converter steel we were unable to produce any large proportion of good castings regardless of the manner in which they were cared for.

"Somewhat later we undertook the manufacture of rudder stocks and stern frames for merchant ships, and our experiences on these castings were even more illuminating than on the smaller castings for ordnance work. The reason for this was that the castings were so long as to give a very great total shrinkage amounting to 5 inches. Our first really conclusive test on these castings came when we were obliged to pour a rudder stock from two heats of converter steel which analyzed as follows: Carbon 0.29 to 0.31 per cent, silicon 0.51 per cent, manganese 0.77 to 1.01 per cent, sulphur 0.057 to 0.066 per cent and phosphorus 0.052 to 0.056 per cent. The result was the casting tearing in three pieces. This casting was poured the same day successfully from electric metal."

The experiences of these people are similar to others throughout the country, that is electric furnace metal of a similar analysis will give good castings where converter metal is more likely to crack and tear.

The prospective purchaser of an electric furnace is interested in the qualifications and limitations of such a melting medium. Often his foundry is at present equipped with a converter or a small open hearth, and he is not anxious to make a change unless future results will



warrant the added expense. In general, the electric furnace offers many points of superiority over other types of steel making equipment. However, like everything else, it has certain limitations.

The most important point is that of quality. Due to the absence of any gaseous matter being blown into the furnace, the steel can be *killed*, readily assuring sound castings. Metal of regular composition is obtained. The temperature is always under exact control, and may be made high enough to run castings of the thinnest sections. As small heats can be taken off at short intervals, the amount of floor space required, and the number of flasks and other miscellaneous appurtenances is kept at a minimum. For these reasons losses in defective work are lower than in any other process of manufacture

John A. Matthews, president of the Halcomb Steel Co., pioneer in electric steel manufacture, presented at the October meeting of the American Electrochemical society, May 2-5, 1917, a summary of the merits of this metal. These are:

1. The chemical composition of consecutive heats, most notable when handling easily oxidized metals like vanadium, chromium, silicon and manganese, can be held more closely to a standard than with any other process.

2. To insure a given final medium, less of these metals need be added, hence there will be less of the oxides of these metals produced in the steel and less to be removed.

3. Heat treating is improved according as composition can be controlled closely.

4. Electric steel usually is more nearly chemically pure than any other steel. Irrespective of whether or not uniformly distributed sulphur is as harmful as is generally believed, it is obvious that the segregation of elements is impossible if they are absent. It also follows that if the segregation of sulphur and phosphorus is not to be feared the percentage of cropping may be reduced and the yield of sound metal increased.

5. Low sulphur in electric steel usually indicates a

prior reducing condition favorable to complete deoxidations, sound ingots, freedom from blow-holes and resulting seams. Quiet metal has less tendency to segregate in the mold, in respect to either metallic or nonmetallic elements and produces metal free from laminations.

6. Alloy additions may be made in the furnace itself rather than in the ladle which increases the probability of thorough assimilations, diffusion and homogeneity.

7. Results indicate that electric steel is less injured by overheating than other steels. It has a wider range of heat treatment and will stand variations in forging and following treatment without injury.

8. Electric steels usually are freer from slag and nonmetallic inclusions than bessemer or open hearth steels.

9. The foregoing characteristics tend toward the production of a steel of better quality. The electric furnace possesses an economic value in its adaptability to the recovery of scrap values, and has a decided advantage over the open hearth furnace in that some alloy scraps do not make desirable additions to open hearth furnaces, or if such additions are made, usually result in a great deal of the scrap metal being lost in the slag. With the widespread and increasing use of alloy it is highly desirable that alloying elements be not lost when contained in the scrap.

The electric furnace is highly adaptable, a feature which is of the greatest importance, and one finding increased use daily. A heat of plain steel may be poured followed by a heat of gray or white iron, or some alloy mix. Consequently, a shop is enabled to bid on a greater variety of work, thus obtaining a greater aggregate tonnage than the one product company. The author has known several companies which regularly handle five or six different classes of metal from the same furnace with no difficulty.

## II

### COST OF ELECTRIC MELTING AND POWER CONTRACTS

THE main point at issue in discussing a contemplated electric furnace installation is the cost of the molten metal at the spout, and it is this feature which settles the argument. If electric furnace metal is going to be too costly it is unwise even to consider such a melting medium, unless the product is of such a character that a few dollars' difference in cost of molten metal may be disregarded. For general foundry work extreme quality is not of enough importance to outweigh this cost of metal.

Electric power is the deciding factor when considering the cost of steel. The cost of this energy varies greatly, being cheap in sections where hydroelectric power predominates, and comparatively high in sections of the country where electric current is produced by steam. Electric current usually is sold under some sort of a sliding scale, and comprises two charges, that for demand, and the energy charge for current actually consumed. The demand charge is fixed monthly and is determined by the maximum amount of current called for at any one time during the period. The energy charge changes according to the total amount of current used in the month. Then there are other clauses covering service in off peak hours; certain clauses covering changes in price of coal, etc. The prospective consumer should understand thoroughly all the details of his contract as a fraction of a cent's difference may mean several dollars a ton on the finished product.

The accompanying Tables V, VI, VII and VIII show different types of power contracts in force in various sections of the country and are typical. Note particularly the curve in Fig. 1 on page 15. With this con-

**Table V**  
**NEW ORLEANS CONTRACT TERMS**

	Kilowatt- hour
<b>Demand Charge:</b>	
First 5 kilowatt hours of demand .....	\$3.00
Next 15 kilowatt hours of demand .....	2.50
Next 30 kilowatt hours of demand .....	2.25
Next 150 kilowatt hours of demand .....	2.00
All over this amount .....	1.50
	Cents per Kilowatt- hour
<b>Energy Charge:</b>	
First 500 kilowatt hours .....	5.0
Next 1000 kilowatt hours .....	3.0
Next 3500 kilowatt hours .....	2.5
Next 45,000 kilowatt hours .....	1.0
All over 50,000 .....	0.75
<b>Fuel Charge:</b>	
A sliding scale based upon the price of coal, which cannot exceed 30 per cent of the calculated energy cost.	
<b>Discounts:</b>	
Ten per cent off for ten days payment on total bill.	
Ten per cent on energy charge for company owning their high tension transformers.	
Fifty per cent off of demand charge if no current is used during peak hours, this period being the time between five and seven p.m.	
Fig. 2 shows power costs per ton of metal, based upon this schedule.	

**Table VI**  
**PITTSBURGH DISTRICT CONTRACTS\***

	Cost per Kilowatt
<b>Primary or Demand Charge:</b>	
First 25 per cent of maximum demand .....	\$4.00
Next 25 per cent of maximum demand .....	3.00
Next 50 per cent of maximum demand .....	2.00
Kilowatt in excess of 1200 .....	1.00
	Cents per Kilowatt- hour
<b>Secondary or Energy Charge:</b>	
First 50,000 kilowatt hours .....	0.9
Next 50,000 kilowatt hours .....	0.85
All over 100,000 .....	0.75
<b>Discount:</b>	
From the secondary charge a discount of 0.005 cents per kilowatt-hour is made on the first 100,000 kilowatt hours for prompt payment.	
Fig. 3 shows actual metal costs based on this schedule.	
*“Electric furnace power from the central station standpoint.” E. A. Wilcox, American Electrochemical society, April, 1920.	

Table VII

## EAST POWER CONTRACT

Eastern power contract\* available to customers with connected load of 200 kilowatt hours or more.

Demand Charge:	Per kilowatt per month
First 200 kilowatts .....	\$1.50
Next 800 .....	1.00
All over 1000.....	0.75
Energy Charge:	Cents per kilowatt hour
First 10,000 kilowatt hours per month. ....	1.5
Next 90,000 .....	1.0
Next 200,000 .....	0.8
All over 300,000 .....	0.6

## Remarks:

Demand determined by averaging 30 minute peaks for first month, this rate to hold for remaining 11 months unless demand is increased.

Five per cent off for prompt payment.

No discounts for off peak use of power.

\*E. A. Wilcox.

tract as shown the added charge based on price of coal amounts to 0.325 cents per kilowatt hour, or approximately \$3.25 per ton of clean castings.

From these varying power schedules some comparison may be had of actual electric energy costs, and the various methods of placing the charges. Each installation usually requires a new power contract with the supplying company unless there are already electric furnaces on the company's line, when a similar contract may apply to the new installation.

Under nearly all schedules a heavy discount is allowed when power is taken in *off peak* periods and naturally it is to the benefit of the foundry to operate in these hours if possible. This usually is accomplished by molding during daylight and pouring all work at night when the off peak hours fall at night. To do this certain concessions such as higher wages must be paid to the furnace and miscellaneous labor. The only objection to this is that a greater amount of floor space is required, and the number of flasks necessary is increased. This tends

## Table VIII

## GREAT WESTERN CO. CONTRACT

**SERVICE:**

This service applies in the entire territory served except in standard voltage of 2200 volts or over.

**TERRITORY:**

This schedule applies in the entire territory served except in Butte and Plumas County.

**RATE (A):**

*Service at 2200 volts up to and including 25,000 volts...*

**DEMAND CHARGE:**

First 200 kilowatts or less of maximum demand \$300 per month.

Next 200 kilowatts of maximum demand \$1.00 per kilowatt per month.

Next 500 kilowatts of maximum demand 75 cents per kilowatt per month.

All over 1000 kilowatts of maximum demand 60 cents per kilowatt per month.

**ENERGY CHARGE:**

First 150 kilowatt hours per kilowatt per month, 8 cents per kilowatt hour.

Next 250 kilowatt hours per kilowatt per month, 6 cents per kilowatt hour.

All over 400 kilowatt hours per kilowatt per month, 55 cents per kilowatt hour.

**RATE (B):**

*Service at line voltage in excess of 25,000 volts.*

The rate is the same as that set forth under Rate (A) above decreased by 10 per cent.

**SPECIAL CONDITIONS:****(A) Total Charge:**

The total charge is the sum of the demand and energy charges given above.

**(B) Voltage**

Service under Rate (A) will be supplied by the company at standard voltages of 2200 volts or more up to and including 25,000 volts as requested by consumer.

Service under Rate (B) will be supplied by the company from standard line voltages as available above 25,000 volts.

**(C) Demand:**

The maximum demand in any month will be the average kilowatt delivery of the 30 minute interval in which the consumption of electric energy is greater than in any other 30 minute interval in the month. The maximum demand on which the demand charge and energy block will be based will not be less than 50 per cent of the greatest maximum demand occurring during the 11 preceding months.

Any demand occurring between the hours of 11 p. m. and 6 a. m. of the following day will not be considered in the determination of the above demand.

(D) All voltages referred to in this schedule are nominal voltages.  
**TERMS AND CONDITIONS:**  
 See preliminary statement, application and contract forms and rules and regulations.

to detract from one of the main advantages of the electric furnace. This issue must be carefully thought out

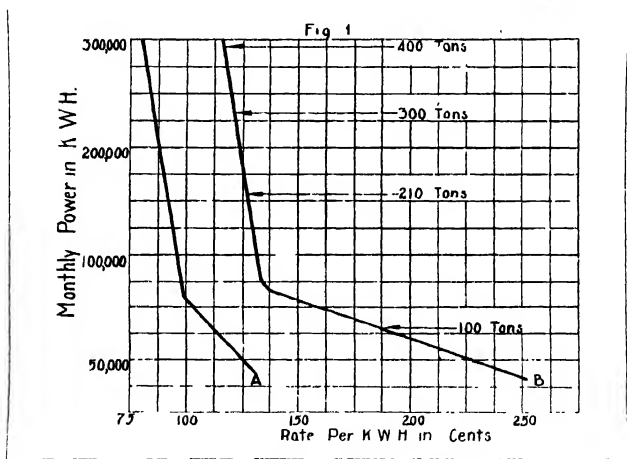


Fig. 1 - Curve A is Plotted from the Rate Schedule, Table V, for the Energy Charge Only Without Added Fuel Charge—Curve B is Plotted from Actual Costs of Energy and Computed Fuel—Note the Great Difference Caused by This Small Item

and preference given to the arrangement offering the cheapest operation.

When the off peak period is short it is possible to arrange heats so that the furnace will not be used at times when the load is heaviest.

### *The Demand Charge*

Another point of importance, especially in the new

shop where tonnages are low for the first few months, is that of demand. As this is a fixed charge regardless of how much energy is used, and its final cost is directly proportional to the tonnage, it is important to keep as low a demand figure as possible. This will mean keeping

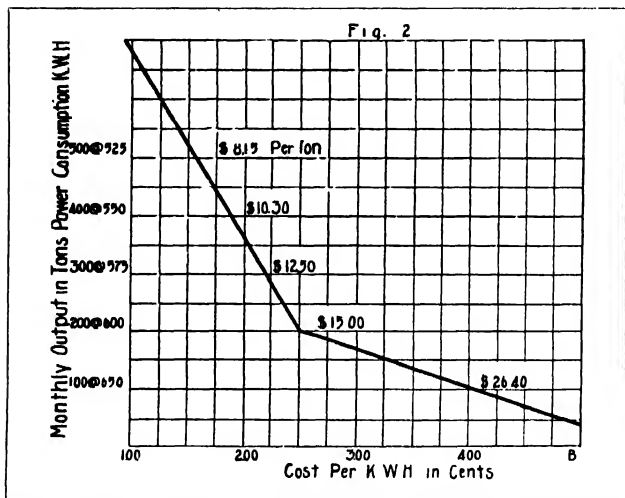


Fig. 2—Actual Costs for Total Power, Including Demand, Energy and Fuel Charge Based Upon Actual Costs

down the power input to the furnace, and will result in the heats taking a slightly longer time.

Reference to Table V will illustrate this point. This power schedule has a sliding demand charge, and was drawn up to apply on the operations of a 3-ton acid furnace the normal capacity of which was 1500 kilowatts. During the first two months operation, the tonnages were approximately 25 for each month. The demand was kept down to 1200 kilowatts costing \$850 or about \$34 per ton. As business increased and it became necessary to make quicker heats, the furnace was allowed to draw



a heavier load and the demand went up to 1600 kilowatts costing \$1150 or \$5.75 per ton based on the output of 200 tons obtained. If the demand had been set at 1600 from the first it would have resulted in a needless expense of \$300 per month.

### *Choosing the Size of Furnace.*

Electric furnaces are made commercially in sizes of from  $\frac{1}{4}$  ton to 6 tons to be used for foundry work exclusively. Of the different sizes two find greater favor

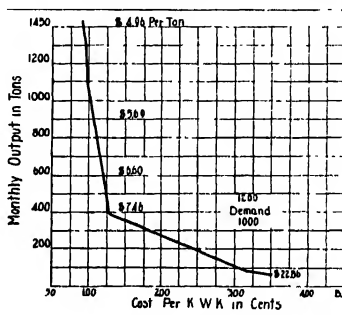


Fig. 3—Actual Costs Per Ton for Power Under the Schedule as Described in Table V

than any others. These range from  $\frac{1}{2}$  to 1 ton, and from 3 to 4 tons. Each size may be overloaded, but these are rated capacities usually favored.

Naturally, the prospective purchaser is interested in knowing which size will best meet his needs. It has been a common experience for a foundry to look ahead to contemplated expansion and buy a furnace too large for immediate requirements. Consequently this later stands idle part of the time. Conversely, the opposite has been true in cases when unseen expansion has occurred due to such conditions as striking oil in adjacent territory, large industrial expansion, etc., where the demand for castings rapidly increased.

It would appear upon snap judgment, that the advantage would lie with the larger size furnaces, due to their ability to handle a larger tonnage over a given period. When all of the points are considered, it appears that this advantage is little, if any. In fact it is the writer's opinion that the shop employing the smaller furnace has a distinct advantage in the great majority of cases provided careful management governs.

In the careful calculation of this problem so many variable points are encountered that it becomes difficult to say positively that a 1-ton will prove superior to a 3-ton furnace. By small furnaces are meant those from  $\frac{1}{2}$  to 1-ton rated capacity, while large furnaces are understood to embrace those from 3 to 5 tons each, sizes larger than this being found infrequently in foundries.

Two main features should be considered in deciding upon the size of furnace necessary. These are: maximum sizes of castings to be made, and tonnage to be handled over a given time. If a company is engaged in manufacturing where castings over 3 tons in size frequently are required, the larger furnace will be mandatory. Similarly, if the company has an assured tonnage sufficient to operate the large furnace to capacity is out of the question to think of a small sized unit. However, many companies are not in such a fortunate position, but are dependent upon a general line of jobbing castings for their income. Some are more fortunate in that a part of their output is used in manufacturing within their own plants. For the latter there is no question but that the smaller unit will prove more suitable. The advantages of the small type furnace may be summarized as follows:

It is much easier to obtain the tonnage necessary for the economical operation of a small furnace than it is for a larger installation.

It has been found in actual practice that of the work

handled in a 3-ton furnace shop, from 80 to 90 per cent could be cast from a small furnace.

On classes of work too large for the small furnace added competition is offered by a large open-hearth shop, always eager to bid on tonnage work.

The power demand is much smaller on the small unit, and during slack times when the furnace is not in steady operation this means a saving in fixed charges of from \$500 to \$1000 per month, depending upon the power schedule.

Naturally the primary outlay will be much smaller on the 1-ton furnace. Further, the building will not need so much floor space due to the fact that smaller heats are poured at short intervals. The building, and crane runways can be built much lighter. The auxiliary equipment such as ladles, sand mixers, mold and core ovens, annealing furnaces, and miscellaneous cleaning equipment are much smaller. The number of flasks needed is much smaller, due to the greater turnover. Many other points might be suggested indirectly in favor of the small unit. However, for further calculations it may be assumed that the cost of the items mentioned varies directly in proportion to the size of melting equipment.

### *Continuous Operation Favored*

A main item in an electric furnace foundry is to be able to run continuously, to conserve the heat left in the furnace from the previous melt. The small unit is favored on this count. Heats of 1000 pounds can be made at a time and thus it becomes easy to keep the furnace in operation by working on different classes of metal. Common steel castings may be made as the main product, and orders for small lots of special metal such as chrome, nickel, or manganese steel castings may be taken with profit. Under these conditions of operation, the cost of conversion becomes low, and with a fair power charge, gray and white iron castings may be made cheaper than in the cupola. Operating in this manner the furnace is

Table IX  
Operating Figures in Various American Shops

Basic Operations		Size heat Tons	Operations Hours	KwH per ton	Time-heat		Electrode cons. per ton	Life of roof Number of	Life of walls Heats
Make of furnace					Hours	Minutes			
Heroult		3 to 5	12	850	5		30 lb. Carbon	75	75
Heroult		6 to 8	12	650		5 to 6	28 lb. Carbon	225	200 to 250
Gronwall-Dixon		3	8	760		3 to 4	21 lb. Carbon	150	200
Heroult		3 to 5	16	800		4 to 5	28 to 30 Carbon	75	225
Greaves-Erchell		6	8	900		4 to 5	57 Carbon*	129	129
Rennerfelt		1	8	787		2:45	14 Graphite	90	195
Greaves-Erchell		1	8	900		2:30	15 Graphite	160	120**
Webb		3	24	650		2:45 to 3	6½ Graphite	100	100
Booth		2½	8	1450		2:30			
Greene		2	16	730		2:15	15 Graphite	75	150
Heroult		6	24	575		3:00	22 Carbon	125	250
'Lectromelt		3	8	700		2:30	28 Carbon	75	125
<b>Acid Operations</b>									
'Lectromelt		3	8	780		1 00	32 lb. Carbon	110	300
'Lectromelt		3 to 4	8	570		1 15 to 1:45	18 lb. Carbon	75 to 100	300 to 400
Greene		2½	8	850		3:00	40 lb. Carbon	142	142
Greene		2	8	700		2:30 to 3:00	15 Graphite	146	146
'Lectromelt		1½ to 2	8	520		1 00	14 Graphite	300	500
Rennerfelt		1	8	700		2:30	20 Graphite	100 to 200	560
Heroult		4	10	650		1:45	15 Graphite		
'Lectromelt		3	8	660		2:30	30 Carbon	50	100
Greene		1½	8	800		3:00			
Greene		2 to 3	8	700 to 800		3:00 to 4:30	10 Graphite	100	100
Heroult		2½	8	635		2:30	16½ Graphite	175	175

All of the figures were given the writer by the superintendents of the various foundries, and naturally show a great variation. However, the general trend of results clearly is shown.

\*This figure is either a mistake or indicates wretched practice.

\*\*It is unusual to obtain a longer life from a roof than a side wall, and if this is correct probably indicates a roof which has been patched up, or else trouble is being had with the walls failing.

kept busy and cheap operating figures, with their attendant profit naturally follow. Table IX gives some operating figures from a number of shops.

Superintendence seems at first glance to offer a problem. How is the shop with a small tonnage able to attract, and hold the high priced man? In the shop operating a 3-ton furnace, a superintendent at say \$5000 a year, melter at \$3000, a foundry foreman at \$3000, and a cleaning room foreman at \$3000 will be necessary. Naturally, in the small shop it is impossible to have such an array of talent. Therefore, the solution is to obtain for superintendent a first class metal man who can handle the executive problems, who can break in his furnace crews, and who can oversee both the molding and cleaning. Such a man is worth \$5000 or more. He will need the assistance of a first class molder who can be elevated to the position of a sub-foreman at about \$175 per month, or \$2100 a year. Under these conditions the size of the superintendent's duties will be just sufficient for him to handle the work with the highest efficiency, and as everything will be always at his finger tips he will function with the least amount of lost motion. In some shops the superintendent walks around and looks wise. Why not put him to producing?

#### *Comparative Production Costs*

Now comes the crucial test in comparing furnace sizes. How much will the cost of finished castings from the two units vary? Several factors must be studied to determine the proper rating on this basis.

#### FIXED CHARGES

Assume conservative figures for output. Using acid operation the 3-ton unit will pour from three to four heats in 8 hours; and from seven to eight in 16 hours. The small unit will pour five to six heats in 8 hours; and from 11 to 13 in 16 hours. Assuming the large heats to be 4

tons each, and the small ones 1 ton, the following figures are obtained:

	$\frac{1}{2}$ to 1 ton unit	3 to 4 ton unit
8 hour operation .....	5 tons	12 tons
16 hour operation .....	11 tons	28 tons

Taking the conservative figure of 8 hour operation the yearly tonnage for the small furnace will approximate 1500 tons, while that for the 3 to 4-ton unit will be 3600 tons.

Assume that the total cost for the one ton shop is \$50,000 and that for the three ton one amounts to \$150,000, we obtain figures on fixed charges of \$7000 and \$21,000. These figures cover all points of depreciation, amortization, repairs, etc., figured on the same basis for both installations.

#### SUPERINTENDENCE

This, as shown before, will amount to \$7100 for the small unit, and \$14,000 for the larger type of melting furnace.

#### COST OF METAL IN THE LADLE

The following figures are taken from actual operating sheets:

Heat Number	Kilowatt Hours Per Ton	
	Small furnace	Large furnace
1st	750	700
2d	700	600
3d	600	530
4th	550	.....
5th	550	.....
Average	630	610

While the smaller furnace has the advantage of a more continuous operation, with its attendant saving in power, the larger unit has the advantage of a higher thermal efficiency, and thus the average power consumption

favors the 3-ton furnace. However, another point must be considered, namely, the demand charge. The demand will be 500 kilowatts for the small furnace, and 1500 kilowatts for the large size. The power companies usually make a fixed charge of so much per KWH of demand. This can be shown in the following table:

	1-ton	3-ton
Average kilowatt-hour per ton.....	630	610
Monthly consumption .....	78750	183000
at 1 cent per kilowatt-hour.....	\$787.50	\$1830 00
Maximum demand .....	500	1500
at 1 cent per kilowatt-hour.....	\$500 00	\$1500.00
Total power cost . . . . .	\$1287.50	\$3330.00
Power cost per ton .....	\$10.30	\$10.10

#### LABOR COSTS

On the small furnace two men will be ample to take care of all melting, charging, and ladles. On the larger unit where greater amounts of scrap are needed a greater amount of help will be required. The following table gives the comparative labor costs:

	Small furnace	Large furnace
1 melter at 75 cents . . . . .	\$ 6.00	\$ 6.00
1 helper at 50 cents . . . . .	4.00	4.00
1 ladleman at 50 cents . . . . .	.....	4.00
2 chargers at 30 cents .. . . .	.....	4.80
1 scrap craneman at 60 cents .....	.....	4.80
	<hr/>	<hr/>
	\$10.00	\$23 60
Per ton .... ..	\$ 2.00	\$ 1.97

#### OTHER ITEMS OF COST

Under this heading are placed refractories, patching materials, electrodes, alloys, ore, tools, water, etc. While the cost per unit to line the larger furnace will be smaller, the efficiency will not be so great, and it is reasonable to assume that the miscellaneous items will average the same for both size installations. The following comparison therefore may be made:

**Small Unit**

Conservative Yearly Tonnage .....	1500
	Cost per ton
Fixed Charges at \$7000.....	\$ 4.67
Superintendence at \$7100 .....	4.73
Power .....	10.30
Furnace Labor .....	2.00
	<hr/>
Total Cost per Ton .....	\$21.70

**Large Unit**

Conservative Yearly Tonnage .....	3600
	Cost per ton
Fixed Charges at \$21,000 .....	\$ 5.83
Superintendence at \$14,000 .....	3.89
Power .....	10.10
Furnace Labor .....	1.97
	<hr/>
Total Cost per Ton .....	\$21.79

Under this final test of actual cost, it is shown that the small furnace compares favorably with one of larger capacity. However, before making any decision it will be best to tabulate as many different points as possible on the two units that all facts pertaining to the problem may have ample consideration. These are given in the following summary and from a careful examination of these the writer has drawn his conclusion that the electric furnace of from  $\frac{1}{2}$  to 1 ton capacity is a commercial success, and, furthermore, except under unusual conditions it is preferable to the larger sizes for general jobbing work, especially where the installation is a new venture into the steel casting business. The points which favor the smaller furnace follow:

- Ability to meet competition
- Adaptability
- Supervision
- Primary costs
- Cost of metal
- Quality of metal



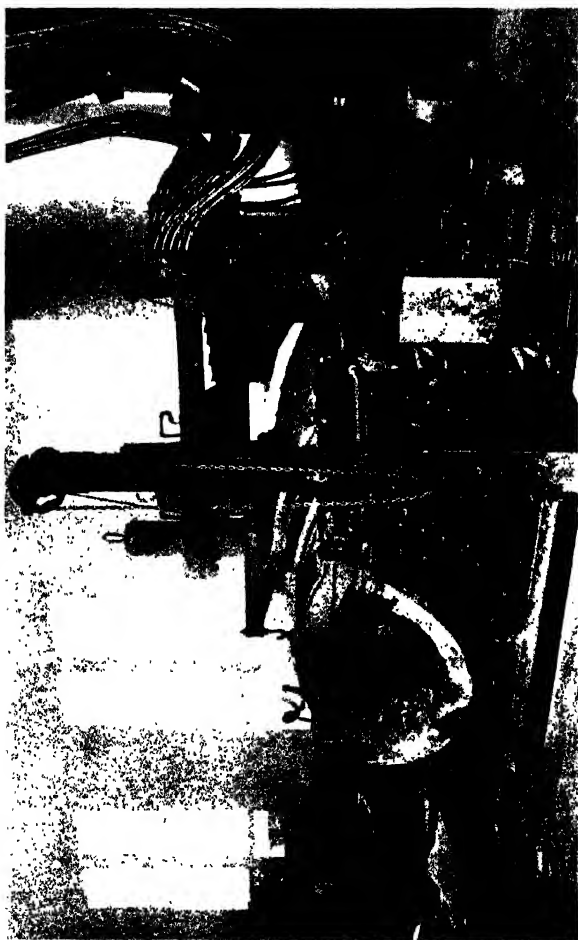


Fig. 4—A Furnace Installed on Floor Level and Tapped Into a Pit—Note the Easy Accessibility of Supplies and Other Furnace Necessities

Ease of handling  
Return in clean castings  
Money tied up in supplies  
Possibilities for profit

In many installations the electric furnace is placed at one end of the shop, provision being made in most cases



Fig. 5—A Furnace on a Platform—Note the Heavy and Costly Concrete Construction Required—in Addition the Crane Must be Used to Bring Everything Needed from the Floor Up to the Melting Platform

for a second unit should it become necessary. Placing the furnace in such a position gives a clear molding floor, and provides a space for all items, such as ladles, etc. Thus the melter has all his accessories directly under his

eye where he can keep close touch, the ladles coming under the steelmaker's supervision.

Such a location permits straight line routing, the scrap being brought in from the yard behind the furnace, and passed down the floor as molten metal with a minimum of handling. Some furnaces are arranged in a side bay so that they are tapped into the main molding bay. This is satisfactory for small furnaces where the electrodes can be handled by hand, but necessitates the use of some sort of swing crane when changing roofs.

The furnace itself may be placed either on a platform or at the floor level. A furnace situated on the floor level is preferable for many reasons. All supplies, such as sand, coke, alloys, scrap, etc., may be brought conveniently to the point in use in trucks or wheelbarrows. The melter can look over the pouring, examine the ladles, etc. The only disadvantage of this setup is the fact that a deep pit is required which in certain localities may allow a seepage of water, but if periodic attention is paid to emptying the pit or to permanent drainage, this offers no great difficulties. The two methods of placing the furnace are shown in Figs. 4 and 5.

The furnace being decided upon the next step will be to the consideration of the product to be made. This tends to determine the make of furnace to purchase and controls the method of operation, whether acid or basic. While many furnace makers claim that their equipment will work as well on acid as on basic operation and vice versa this is not strictly true. Certain furnaces are intended for rapid acid operation and in practice prove too fast for the slow refining necessary for good basic steel. Again, furnaces designed for basic conditions are far too slow for the rapid melting necessary under heavy acid steel production. Therefore the next chapter will give data on the examination of product which will determine whether acid or basic operation is to be used.

### III

#### FACTORS TO BE CONSIDERED IN CHOOSING THE TYPE OF FURNACE

**P**ERHAPS the greatest point in favor of the basic process is its ability thoroughly to deoxidize and desulphurize. Therefore, its use is mandatory for any class of product depending upon the absence of these elements for its quality. However the acid process is noted for its speed and cheapness of conversion and naturally is favored for use wherever possible.

##### *The Basic Furnace*

The various conditions or products which may be served better by a basic furnace are summarized under the following classifications:

##### FOR MANGANESE STEEL

Manganese steel due to its high percentage of manganese and the affinity of this metal for silica to form a manganese-silica oxide slag rapidly slags out an acid hearth. However, manganese is negative to both dolomite and magnesite, the usual constituents of a basic hearth. Naturally, if manganese steel is to be made regularly in a furnace the basic lining is essential. If manganese steel is to be made only at rare intervals, it can be produced on an acid hearth by adding the alloy to the ladle in a molten condition.

One of the great problems of the manganese steel shop is the recovery of heads, gates, spill, etc. This is simple when using a basic furnace, as this scrap may be remelted with a small loss of manganese. Previous to the advent of the basic electric furnace, it was the custom to remelt this scrap in an air furnace with attendant high loss.

### FOR HIGHLY REFINED GRAY IRON

For such products as piston rings, pressure cylinders, valves, etc., an iron is required which is soft and of a tight, dense structure. The basic furnace, due to its powerful desulphurizing features is growing in favor for such purposes. Sulphurs have been made as low as 0.009 per cent, and strength far higher than ever obtained from the cupola metal have characterized electric iron. For large tonnages duplexing with the cupola is possible, while the basic furnace offers an unexcelled method for using cast iron borings and turnings.

Under this heading may also be classed a great variety of alloy irons used for such special purposes as the following: For heat, flame, gas, fume, and acid resisting castings; iron for special electrical purposes; special white irons for abrasive purposes, etc. The alloys in common use are chromium, nickel-vanadium, silicon, and manganese. As these are higher in price, the economy in using them is a prime necessity especially scrap recovery values.

### FOR REMELTING ALLOY STEELS

Due to its de-oxidizing features, the basic process is of great value in recovering such costly alloys as chromium, manganese, vanadium (partially), molybdenum, nickel, and other alloys coming into wider use such as uranium, zirconium, and boron. These alloy steels may be remelted with only the slightest losses under careful operation, and when the increased use of such metals is considered it is readily seen that this is an extremely important qualification.

### FOR HIGH QUALITY METAL

This feature covers such classes of steel as may require extensive heat treating and machining operations in which the cost of molten metal is the smallest factor, and where quality and regular composition are

items of the greatest importance. In this category may fall cams, gears, steels to be operated under pressures or at high speeds, or steel to be used in cases where a failure would cost more than the initial price of several castings.

The basic process, due to the fact that the steel may be held in the furnace indefinitely offers perfect conditions for regularity of composition. The steel may be ready to tap and a test sent to the chemist and the heat held for its final adjustment, dependent upon his analysis, without the least ill effect. This feature is not found in any other method of steelmaking. Further, the metal may be held under a carbide slag until the last trace of gas is dissipated, and may be poured with the knowledge that it is *right*. Where heat treating is of importance such conditions of real quality and regularity are of vital necessity if rejections are to be kept to an absolute minimum.

#### WHERE ECONOMIC CONDITIONS FAVOR

It may be that a shop will have the opportunity to obtain enough special work to warrant slightly higher operating costs to obtain a greater tonnage and more regular furnace operation. For instance, this might happen in certain localities where it would be possible to make steel castings, gray iron castings, and manganese steel. While the conversion costs would be higher, the better operating figures from steady operations, and the decreased overhead, together with the higher profit from specialties might amount to enough to overcome this added cost of conversion in favor of the basic furnace.

A second case would be where it was impossible to obtain acid scrap except at a high premium for low sulphur and phosphorus. In such a case it would be a question as to whether cheap basic scrap and high conversion figures would be cheaper than high priced acid metal and low conversion costs. This can be better shown by a

table of costs made up by a company which faced this condition. As soon as it was found that it was necessary for this company to have low phosphorus, low sulphur scrap, the metal dealers immediately raised their prices on this class of steel to \$22 per ton, while selling ordinary basic, open-hearth scrap at \$12. The solution to this problem was the decision to operate by the basic process until satisfactory scrap could be obtained at a fair figure, and large amounts of basic scrap were contracted. After several months' operation the scrap dealers came to time and basic operations were discontinued. The comparative costs follow:

Conversion Costs		
	Basic	Acid
Labor .....	\$ 1.67	\$ 1.33
Power .....	9.00	6.00
Repairs .....	4.20	2.10
Slag and miscellaneous.....	1.00	25
Alloys .....	1.60	2.35
	<hr/>	<hr/>
Scrap @ 3 per cent.....	\$17.47 12.36	\$12.03 22.66
	<hr/>	<hr/>
Cost of molten metal.....	\$29.83	\$34.69

In this particular instance the balance was in favor of the high conversion cost and cheap scrap to the amount of \$4.86 per ton of molten metal or approximately \$7.48 per ton of cleaned finished castings.

A third case would be under circumstances where it was necessary to make exceedingly low phosphorus and sulphur metal, but as this is rare it does not warrant special mention.

### *The Acid Furnace*

The foregoing summarize the more important considerations which dictate basic rather than acid operation. Next we may study the various points which favor

the acid lined furnace. These are set forth under their various headings as follows:

#### FOR ORDINARY CARBON STEEL

For plain steel castings the acid process is much superior to basic operation. Furnaces designed for acid operations use higher voltages than those intended for the lengthy refining operations of the basic furnace. Consequently, the time per heat is lowered and a greater tonnage can be obtained over a given period. Shorter time of melting means a shorter period where radiation loss is effective which cuts the power consumption. This quicker operation means less electrode consumption, and lowers refractory costs. There is no large volume of limey slag to heat, and splash on the furnace walls. This means a further saving in power, and increased refractory life. Old molding sand is used for slag making which is far cheaper than a mixture of lime, fluorspar, and ground coke. Common silica sand is used for bottom making and for patching purposes being considerably cheaper than either dolomite or magnesite.

Due to the absence of this heavy slag body, and to the better heat resistance of the acid hearth, it is possible to make acid steel much hotter than basic. This is a great advantage where small size castings constitute a large portion of the shop's output. An acid slag will not attack the ladles in the same manner as will a basic slag, nor will it slag off the bricks on the stopper rod as sometimes happens on a hot basic heat. These points make for cheaper ladle upkeep, an important item in a year's time.

An acid furnace is much easier to operate than a basic unit and can be handled with less labor. Considerably less brick work is required on roof building, and repairs to the side walls and hearth are negligible. An acid bottom is kept in repair easier than a basic one due to the fact that sand used for patching tends to sinter



in better than the higher melting point basic material. Furthermore, an acid hearth will not come up in lumps like one made of magnesite, and does not require any tedious slagging off except in unusual circumstances.

The main argument against acid operation is that the quality of the steel made is not as high as that made by the basic process. While it is perfectly true that a higher grade of steel can be consistently made by the basic process. The author does not consider that such added quality is necessary for the majority of steel castings. Not only will acid furnace metal satisfy all existing specifications for steel castings, but in the majority of cases, where a first class man is in charge of melting operations, it will give tests of from 5 to 15 per cent above the required figures.

While acid steel is probably not exposed to as vigorous a reduction as basic metal, it tends to give a higher degree of solidity in the mold, especially on green sand work, which results in a lower percentage of defective castings.

However, in one physical factor basic steel is superior to that made by the acid process, and that is in the comparative freedom from hot checks, cracks, and tears in castings made from basic steel. Acid steel if poured too hot in certain types of casting is likely to tear and greater care is necessary in the use of heads, brackets, *dogs*, and fillets. After a molder foreman once understands this peculiarity of his metal, little trouble will be encountered.

Due to the nature of acid slag, tending to harden on exposure to the air, little trouble is experienced with slag inclusions where, a top pour ladle is used, this being common practice in shops which operate furnaces of the smaller sizes. The use of a bottom pour ladle which is the only real satisfactory vessel for pouring steel will prevent such troubles.

### FOR ORDINARY GRAY OR WHITE IRONS

Unless extremely low sulphurs are required in the iron the acid furnace will prove satisfactory. A good grade of scrap will be necessary for machine castings, and often by the judicious use of pig exceptionally high grade irons can be produced. The big feature of the electric furnace for melting iron is its ability to superheat, and this can be effected as well under acid as basic conditions. For certain classes of metal varying percentages of steel may be used, resulting in an iron of lower phosphorus and sulphur content with its attendant higher strength. Castings which formerly were poured of high phosphorus stove plate iron can be readily poured from ordinary analysis metal with no danger of a misrun. Under certain conditions synthetic iron may be made from a steel base with a phosphorus as low as 0.02 per cent which exhibits unusual qualities of strength and toughness.

### FOR INFREQUENT SPECIAL ALLOY MELTS

Such alloy steels as nickel, chrome, vanadium, silicon, and manganese up to about 1.50 per cent may be made on the acid hearth. Manganese steel can be made by adding the alloy to the ladle in the molten condition. The great disadvantage is the fact that these alloys cannot be recovered on the remelt which makes this method uneconomical.

### COMPARES OPERATING COSTS

To determine the actual difference in conversion costs between the acid and basic processes, experiments were carried on by the writer. The furnace was a well known make rated at 3 tons' capacity, operated under both processes by the same men, and under exactly the same conditions as to number of heats per week, etc. The scrap used was medium size and possessing approximately the same amount of phosphorus and sulphur so that there

was no great attempt to reduce either of these elements when operating basic.

The steel made in both cases was to be used for steel castings only, and was made to satisfy the standard specifications of the American Society for Testing Materials for soft to medium grades. The metal made analyzed as follows: Carbon 0.22 to 0.26 per cent; manganese 0.60 to 0.80 per cent; silicon 0.25 to 0.30 per cent; sulphur and phosphorus below 0.05 per cent.

The slags on basic operation were made of a good grade of burned lime, gravel fluorspar and crushed coke. Acid slag was made of old molding sand. Slags in both cases were of such an amount as would be used under the best of operating practices, and all heats were made under the highest of metallurgical care.

The same number of heats was taken for comparison, being taken at a period when two heats were being made daily averaging 4 tons per heat. The metal was being poured into small and medium size work, each heat pouring close to 35 flasks. The operating conditions are tabulated as follows:

	Acid hours	Basic hours
Time of first heat.....	1:30 to 1:45	3:00 to 3:30
Time of second heat.....	1:15 to 1:30	2:30 to 3:00
Kw. Hr. per ton 1st heat.....	625	885
Kw. Hr. per ton 2d heat.....	550	770

From these results were calculated data on what could be expected under both methods of melting. These are shown in the accompanying Table X.

This gives a balance in favor of acid operating of \$5.76 per ton or approximately \$8.87 per ton of finished casting based on a return of 65 per cent of the molten metal.

In addition to the differences in metal costs other indirect advantages are possessed by acid steel. Hotter metal is obtained and fewer castings are lost from mis-

runs. The percentage of castings lost from slag pockets is also less, due to the greater tendency of acid slag to clean itself from the metal. Basic metal refined under a heavy carbide slag, often gives difficulty in green sand molds, causing *blowby* work. While this never has been

Table X  
ACID VERSUS BASIC OPERATION  
Three to Four Ton Furnace  
Conditions of Operation

	Power kilowatt hour/ton	Time hours
1 heat per day . . . . .	A 600-650	1:30-1:45
	B 875-900	3:00-3:30
2 heats per day . . . . .	A 550-600	1:15-1:30
(2d heat) . . . . .	B 775-825	2:30-3:00
3 heats per day . . . . .	A 475-525	1:10-1:30
(3d heat) . . . . .	B 625-700	2:15-2:25
24 hour operation . . . . .	A 450-500	1:10-1:20
(Average) . . . . .	B 575-625	2:15-2:25
Item	Acid	Basic
Number of heats poured . . . . .	12	7
Tonnage—molten metal . . . . .	36 plus	21 plus
COST COMPARISONS		
Labor: 3 melters @ 75c hr.	Dollars	Dollars
3 helpers @ 50c	per ton	per ton
6 laborers @ 30c . . . . .	1 23	2.11
Power: Acid 500 KwH @ 2.00c		
Basic 600 . . . . .	10.00	12.00
Electrodes: Acid 14 pounds @ 6c		
Basic 22 pounds . . . . .	0.84	1.32
Refractories and patching materials . . . . .	1.00	2.50
Slag making supplies . . . . .	0.10	1.00
Alloys . . . . .	0.90	0.90
Conversion cost . . . . .	\$14.07	\$19.83
Scrap metal:		
\$18.00 per ton @ 5% melting loss	18.90	18.90
Cost molten metal . . . . .	\$32.97	\$38.73

explained satisfactorily it seems that some dissolved carbide becomes liberated upon reaction with the acid mold material causing an evolution of gas often sufficient in volume to ruin the casting.

#### CHOOSING A FURNACE

At present approximately 15 or 20 makes of electric

arc furnaces are available on the American market. Of these few are of such a design as to warrant successful operations from a commercial standpoint. In number installed the Heroult furnace, one of the oldest on the market, still leads.

The Heroult furnace, while being used in some cases on acid operations, is strictly a basic furnace. The power usually is arranged to give from 110 to 130 volts on the high side, and from 70 to 90 on low. This is to supply a short arc during refining with its attendant low radiation making this finishing period less severe on the roof and side walls. The furnace is cylindrical in shape with two charging doors on opposite sides and the pouring spout in front. This arrangement is excellent for ease of charging and for patching, working slag, etc. Of the 181 furnaces of this make in use probably 175 are in basic operation, a great majority being used for the production of ingots and alloy metals.

The majority of Ludlum furnaces are in use either for gray iron refining or for making steels of the finest quality. This furnace is of an elliptical shape with two large doors, one extending the full width of each end. The walls slant up and out tending to retain the shape of the banks, and resulting in a long refractory life. The three electrodes are in a straight line down the center of the furnace, and are connected three phase. For the production of tool steels this furnace is giving satisfactory operating results, but seems to be handicapped in the rapid operation in a foundry.

The Greaves-Etchells furnace is unique in that it uses the principle of the conducting hearth implying basic operation only, as an acid refractory will not conduct the current. Magnesite when hot is a good conductor of electricity, and it is this fact upon which the furnace operations are based. The transformers are Scott connected, two phases going to the electrodes and the third being

direct connected to the hearth. By an arrangement of switches the power is so arranged that at the start of operations when the hearth is cold, and non-conducting, all the current enters through the electrodes, the hearth connection being thrown in when a pool has formed. For fine steels containing high melting point alloys such as tungsten, etc., this probably offers advantages due to the bottom heating and to the agitation caused by convection currents emanating from the conductive hearth.

The Greene furnace has had a rather rapid increase in numbers during the past few years. The furnace is a rolling cylinder placed with the axis horizontal in each end, and a small pouring spout in front. The shape of the hearth therefore is oblong, the three electrodes being in a straight line. The melting is slow for an acid furnace.

The 'Llectromelt or Pittsburgh furnace is typically an acid furnace designed for quick operation. It is three phase and is made high speed by using a high power input. The melting down voltage is about 180 and the refining or finishing about 120. Consequently heats can be melted in a short time. The normal power input is high for the slow refining necessary to good basic steel, but as this is a feature of the transformer rather than the furnace, it could be easily lowered. At present several basic installations of this furnace are operating satisfactorily, but best results have been obtained in the acid process.

Other furnaces operated successfully upon one or the other of the two types of lining mentioned might be enumerated, but those which were briefly noted were the makes with which the author has come in contact.

## IV

### LINING THE BASIC FURNACE

**A**N ELECTRIC furnace, like any other machinery, always must be kept in the best of condition if the best results are sought. While a furnace is merely a steel shell, lined with brick, and on first thought to keep it properly lined would seem to offer a simple problem, such is far from true. The economical operation of an electric furnace, and the steady production of high class steel implies a minimum of trouble with the refractories used. The brick used in furnaces are rather costly and the labor required for roof and wall building constitute an important item in the foundry. The reduction of these items as much as possible is one of the basic points required of a good melter, and naturally is made possible by obtaining as great a number of heats as can be had. Hearth trouble is another point of great difficulty and often results in a heat of defective steel, caused by pieces of the bottom material coming up and throwing back the slag.

The only real teacher of the many small points necessary for steady, economical operations is experience, and often the lesson is learned at great cost, both to the melter and to the company.

When a furnace is installed in a new shop, it consists of the electrical equipment, and the furnace shell. Usually the manufacturer sends a man to start off the equipment. He remains until the first ten or twelve heats have been poured. The furnace then is accepted by the company and turned over to the melter. If he is an experienced man there probably will be no difficulty, but the trend in many shops has been to take a helper, or some other similar type of man and make him a melter. It is foolish to expect such a man to acquire from the

manufacturer's representative in a few heats the experience necessary to make good steel. If this man formerly has been an open hearth or converter man he will, in all probability, be able to make good steel. But he will be unable to attain economical operation in his furnace, as such equipment is vastly different from any of the older processes of manufacture. Therefore, it is not uncommon to note the great variance in results obtained on similar furnaces making the same classes of steel.

The initial step is bricking the furnace preliminary to putting in the hearth. While different methods of laying the brick are followed depending on the make of furnace, for the purposes of illustration the most common type of furnace, the three phase direct arc will be considered. These may be represented by such makes as the Heroult, Pittsburgh, Ludlum, and Greenc, which while of different hearth shapes are handled in the same manner.

Furnace shells always are built deeper than required to give a high factor of safety, and to enable the furnace to handle heavy overloads if required. This extra depth generally is filled with some sort of a cheap, and medium refractory material, the most common being fire brick. Straight brick are used, and are laid on the flat side, two high. First about one inch of a stiff fire-clay mud is placed on the shell. The initial course of brick are set into this, care being taken to make all joints as tight as possible. As these brick constitute the last line of defense in case of serious bottom trouble, it is as necessary to take as much care of this operation as on the hearth itself. After the first layer of clay brick is set the surface is washed with a thin, fireclay slurry, the mixture being forced down into all cracks by steady sweeping with a common broom. When no cracks are seen the second layer may be laid.

The brick in this layer are placed in the same manner, with the exception that only about  $\frac{1}{4}$  inch of clay mud



is used, of such a consistency that it tends to ooze up through the joints as the brick are forced together. When the course is complete, the mud slurry is used again as before mentioned.

Progress from point will depend upon the method used to form the hearth, of which there are two. These are as follows:

1—Forming complete hearth of grain magnesite.

2—Forming the hearth shape with magnesite brick, requiring only a thin area of grain magnesite.

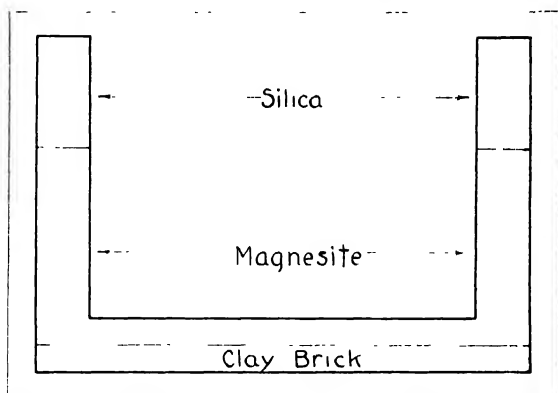


Fig. 6— Simple Method of Laying Brick for Hearth and Walls

#### First Method

If the first method is to be used the brick will be laid as shown in Fig. 6. On laying the first course of magnesite brick, care must be used to form a good bond with the preceding clay course. This is accomplished best by the use of sodium silicate or as it is more commonly known as *water glass*. This is a viscous liquid, which upon drying hardens into a true silicate with good bonding qualities. As it hardens quickly, only small sections are laid at a time. The clay course is swept free of any

superfluous fireclay and is ready for the magnesite brick. Each brick is dipped into the sodium silicate so that it is thoroughly covered and is quickly shoved into place. This operation is continued across the entire furnace, all cracks are filled by pouring a small amount of the silicate into them, and the second course is laid in a similar manner.

Some furnace men prefer to lay the magnesite brick in a bed of finely ground magnesite, contending that a basic brick should be laid in material of its own composition. While this is true from a chemical standpoint it is not so in practice. If the hearth gives way the hot metal is allowed to run down upon these brick. The powdered magnesite between the brick provides no bond, and the chances are that the metal will displace the filler and go through to the clay brick. With the sodium silicate, a bond is produced as strong as the brick itself and there is no chance for the metal to go further. Consequently, when the heat is poured it often is possible to patch directly on these brick with no shutdown required to clean the hearth of set steel. That this is important in eliminating a shut down requires no argument. The main point of adverse opinion on this method is the fact that an acid binder will slag out the basic brick. This would be true if it were placed in a position where high temperatures were constant, but under hearth conditions where these high temperatures are infrequent, this argument is a fallacy. The author has seen cases where several heats in succession were made directly on the bottom brick, and there was no vestige of erosion other than the small amount of spalling caused by changes of temperature. Cases also were noted where powdered magnesite was used, and in each instance the metal went through to the clay course. Another reason brought forward in favor of powdered material over the cement is the consideration of expansion, the exponents of the former claim-

ing that any small clearance between the brick is taken up when the furnace becomes hot. They state that a brick set in sodium silicate has no means of expanding, and is likely to buckle, causing hearth trouble. While this argument is sound theoretically, the actual facts are that the temperature of this course is never high enough to cause trouble from a material with such a small expansion as magnesite.

#### *Laying the Side Walls*

As soon as this second course of magnesite brick is laid it is time to begin on the side walls. These will be laid of 9-inch magnesite brick, sufficient keys being used to make the circle. These brick are laid dry, and are fitted rather loosely, about  $\frac{1}{4}$  inch clearance being allowed to the lineal foot. Such a tolerance is continued until the walls are within a few courses of the metal line, when this expansion is increased to about  $\frac{1}{8}$  inch between each two bricks. Often, powdered magnesite is used between the bricks, but this is not at all necessary and is only an added expense.

The height to which these basic brick will be laid depends upon circumstances. Formerly it was the custom to lay basic brick for a few inches above the slag line, the remainder of the furnace wall being laid with silica brick, but in the last few years the use of basic material for the entire wall has increased. This point will be covered more fully under special refractories. Some analyses of refractories used are given in Table XI.

Assuming that silica brick will be used from the slag line to the roof they will be laid dry the same as the magnesite. Often, a course of some neutral refractory is laid between the acid silica and the basic magnesite, the more common being chrome brick. Results have not proved the necessity for this, although there is nothing against such a procedure except the high cost of chrome. These silica brick are laid with an expansion tolerance of

not less than 3/16 inch per foot, which will be taken up quickly during the heating preliminary to burning in the hearth.

When the brick are laid up to the proper height, the jambs are placed and the arches laid. Special brick with

**Table XI**  
**ANALYSES OF REFRACTORIES USED**

	A	B	C	D
Silica . . . . .	95.50	97.20	95.40	95.95%
Alumina . . . . .	1.53	1.40	1.70	1.69
Iron oxide . . . . .	.75	.20	.40	.51
Lime . . . . .	2.13	.76	2.00	1.20
Magnesia . . . . .	11	.35	..	.16

A Harbison-Walker Co., U S A

B General Refractory Co., U S A

C English brick.

D German brick

From "General Metallurgy" by H O Holman.

Locality	Magnesite Brick		Iron and Al oxide	Silica
	Magnesia	Lime		
Syria . . . . .	85.31		9.05	4.70%
Norway . . . . .	83.60		6.60	9.30
Greece . . . . .	86.50	3.76	6.64	3.10
U S A . . . . .	93.03	4.20	.72	2.16
U S A . . . . .	87.66	1.19	9.29	2.05
U S A . . . . .	90.22		8.28	1.38

"General Metallurgy" by H O Hofman

Calcined Dolomite			
Silica . . . . .	1.66	2.50	1.40
Iron and alumina oxide . . . . .	4.80	3.99	3.75
Lime . . . . .	56.50	57.32	57.30
Magnesia . . . . .	35.83	34.95	37.38
Loss on ignition . . . . .	1.06	1.00	60

"Metallurgy of Steel" by F W. Harbord

"Chemists and Metallurgists Handbook" by Ladell

Dead Burned Magnesite			
Magnesia . . . . .	89.15	79.20	86.42
Lime . . . . .	2.40	3.05	1.68
Silica . . . . .	2.00	10.30	7.00
Iron and Al oxides . . . . .	5.65	7.10	4.75
Loss on ignition . . . . .	15	35	15

NOTE:—Analysis does not always show a first class magnesite for furnace purposes. Some natural magnesites, after being burned, show excellent qualities such as low silica and high magnesia, but are of no use for patching due to their lack of bonding qualities. The highest grade material is made by crushing magnesite with iron ore and burning until in a sintered condition. The iron combines with the magnesite to form a refractory which has perfect furnace properties, that of good resistance and fine sintering features. A refractory manufactured in this manner will nearly always show a decided color such as a dark red to brown, or sometimes even a dark steel blue. Light colored magnesite of a white gray or light brown color will in the majority of cases prove unsatisfactory.

rounded corners are used for the jambs. These are staggered for added strength. For the best results, these brick should be dipped in sodium silicate, or some other refractory cement that more strength may be had by bonding.

The arch brick should be set in the same manner, and it is always better to lay a two high arch if space permits. As the arch is the weakest part of the lining, great care should be exercised to obtain a true curve, and plenty of refractory cement should be used. The brick used should fit snug enough so that any pressure only tends to bind it tighter. After the arches are completed, pieces of brick are fitted in to make a level surface upon which the roof will set.

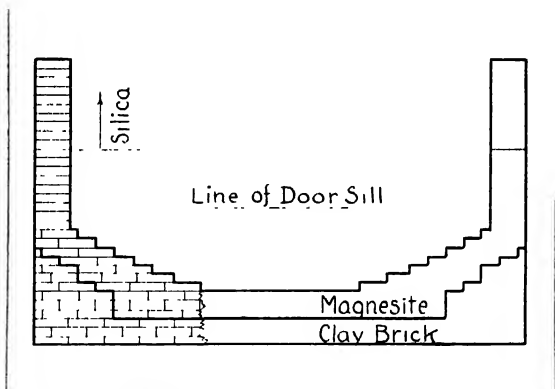


Fig. 7- Second Method of Building Hearth by Offsetting Brick

### *Second Method Suggested*

With the second method of building the hearth to shape with magnesite brick a similar procedure is followed as far as the first two courses. From this point, the brick will be offset, the amount for each course depending upon the shape of hearth desired, the size heats for which the hearth will be laid, etc. The way such a setup appears is shown in Fig. 7, the dead corners being laid with clay brick for cheapness.

The cost of the two methods is about equal, the first requiring less magnesite brick, but more grain magnesite.

The second reverses this condition. In the long run, the second method is far superior to the first for many reasons. These are as follows:

The second\* method gives a great saving of time and power required in the burning operation.

With no dead corners to burn in, a better bottom is assured as the magnesite may be spread more evenly, and a more uniform burning takes place over the entire hearth.

With the approximate shape already laid out, it is easy to build the hearth to proper size without giving an undue depth in the center.

With such a secondary brick bottom, the odds are that the metal always will drain clean, even though a bad hole may form, allowing easier patching.

That these points are appreciated is shown by the ever increasing number of hearths made in such a manner.

### *Building the Roof*

Roofs used on electric furnaces are in the great majority of cases made of silica brick, although recently there have been quite a few instances where carborundum brick have been used. However, their cost is so great that it is a question whether the added life will counteract such an excessive price, although the points in their favor are numerous. All furnace makers supply with their equipment two roof rings. One is maintained as a spare, to keep a roof always set up for an emergency. This ring is set around a form shaped to the desired contour upon which the brick are set. Many ideas are in vogue for making a form, the use of wood, cement, and iron castings being common. As this is a fixed asset it is necessary that some sort of a permanent arrangement be made as every roof will necessitate such a form for its construction. A form made of cast iron is more satisfactory than any other. It may cost more at the start, but its many fine features rapidly will pay for the extra expense.

In making this casting, a sweep can be used, which saves the cost of a pattern. An iron form is smooth, easy to handle, indestructible, and does not tend to warp or change in size as does a wood form. It may be made of rather thin section, and is cheaper to construct than a similar shape of concrete.

Two ways of making a roof are suggested. These involve using standard shapes, or using patent brick. The patent brick are made of a special shape to exactly make up the roof. Consequently, they are easier to lay and a saving in time is effected. Due to their better fit, longer life is obtained than from roofs made of standard shapes. A comparison of costs between the two methods depends greatly upon the continuity of operation. Under conditions of steady operations, where from six to 10 heats per day are being made, the patent roof will give superior service, due to the fact that the brick are considerably larger than standard shapes, and that there is little chance of the roof contracting due to cooling down. Under intermittent operations where the roof is allowed to cool over night, the patent bricks, of large size, tend to spall and crack badly and the service obtained is not nearly so good as if ordinary silica brick are used. As a patent roof costs considerably more than one of common brick there must necessarily be sufficient greater life obtained to overcome this extra cost.

Under conditions where only a few heats are made each week, a roof made of common fire brick probably will prove more satisfactory than one of any other kind of material. The roof brick are cheap when compared to silica refractories. They may be made to fit perfectly by grinding to shape on an abrasive wheel. They do not tend to spall, but burn in nicely and give a comparable life in number of heats.

Regardless of whether patent or standard brick are

used there are certain points of importance to consider in laying the roof. These are as follows:

Some arrangement must be made to take care of expansion when bringing the roof up to steel making temperatures.

A similar arrangement must be made to prevent any slipping of the brick should it become necessary to allow the roof to cool.

The brick must be so laid that there will be neither bulging nor sinking after operations have commenced.

Expansion is handled by expansion strips, which may be made of any combustible material, such as wood, paper, cloth, etc., which will burn out as the temperature rises. The number of expansion strips to use will differ, depending upon the regularity of operations. If continuous operations are assured, rather heavy strips will be used as expansion will be taken up over the first three or four heats. In this instance wood strips are preferable, shingles being an excellent material, and are used to give an expansion of approximately  $\frac{3}{16}$  inch. Any loose brick can be tightened by driving in small wedges, enough being used to insure sufficient tightness to allow lifting the roof upon the furnace.

For intermittent operations, expansion allowance of about  $\frac{1}{8}$  inch per foot is preferable and to allow this paper can be used between the brick. Magazine pages are excellent as they can be quickly prepared of any thickness, and readily burn out on the first or second heat.

To prevent the brick slipping they are so laid that each brick is tied in. By using keys and wedges throughout, this condition is attained, and by using a severe starting angle each brick is resting against the one behind it in such a manner that there is small possibility of a brick slipping through.

#### *Causes of Bulging or Sinking*

Bulging or sinking in a roof is the direct result of too light brick laying or *vice versa*, and is only over-



come by an exact computation of the expansion which will occur. The best method of overcoming this, is by recording carefully the exact manner in which each roof is laid, and watching it throughout its life. If it is found to bulge too much, the record of building is examined and on the next, expansion strips of a slightly greater thickness are used.

In shops where steam is available, a coil may be laid under the roof form, and free coursing of steam always allowed. This tends to dry the brick slowly, and always keeps the brick warm. The result of this is found in a great increase in the number of heats possible. Most roofs on the first few heats spall badly and often two or three inches of effective refractory is lost in this manner. This is the direct result of moisture under the influence of a too rapid heating. However, with a perfectly dry roof a rapid heating up will not affect it in the least. The cost of the steam is negligible when compared to the saving in roof refractories, time lost for repairs, and unnecessary labor.

#### *Dry With Wood Fire*

If it is impossible to obtain steam for drying, an excellent method is to block up the roof on bricks several hours before it is to be placed in operation and build a wood fire under it. This fire is started slowly, only enough wood being used to give a series of feeble flames. After the roof becomes blood warm these fires can be gradually increased until the brick are red hot on the under surface. The roof is kept at this temperature until ready to place on the furnace when it is quickly lifted and set. By this time all of the residual moisture has been removed and when the arc is thrown on, the roof gradually expands without spalling.

#### *Making the Bottom*

The roof being ready and the walls laid, the next step

preliminary to making steel is building the hearth or as it is commonly known *bottom making*. There are three ways of performing this operation as follows:

1—To ram in the complete hearth at one operation and bake until set.

2—To ram in a layer at a time, bake, ram in, etc., until the desired contour is obtained.

3—Set electrodes in the hearth and gradually sinter in the refractory until the bottom is of the desired shape.

While ramming the entire bottom is quick and easy on the operator, it is unsatisfactory in that it becomes an impossibility thoroughly to sinter through the entire hearth depth at one such operation. Assuming magnesite is to be used for the hearth, it is laid out in piles of about one sack each, probably 200 pounds. If desired, a small amount of binder such as open hearth slag may be mixed and used. On the lower courses this slag may be used about one to six, gradually tapering down to about one to 12 for the upper section where the steel will lay. Care must be exercised in the selection of this slag to obtain a low phosphorus content or one of the main basic features will be destroyed and the steel will pick up this troublesome element from the bottom. If basic, open-hearth slag is used it must be low in phosphorus, which is rather unusual, so it is better to use slag either from the acid electric or the acid open hearth. This slag has a much lower melting point than magnesite and will melt and flow around the grains of the latter forming a true bond during the setting. If too much is used, the hearth's resistance to high temperatures will be weakened; if too little, there will be insufficient bond for the magnesite.

In addition to this some sort of a bonding material must be used to hold the refractory together while being rammed into place. There are many different classes of material used for this purpose such as tar, pitch, glutrin, sodium silicate, etc., most of them tending to burn out during the sintering operation.

As tar is the most common its use may be assumed. Some sort of a pot must be made to melt the tar, a good grade of roofing tar being acceptable. As soon as melted, a heavy coat should be brushed over the bottom brick, and the first magnesite mixture quickly started. The tar should be mixed with the refractory in sufficient quantity to enable it to be rammed tight. Great speed is essential that each layer may become part of the previous one without the tar setting. Air rammers are used and this procedure is continued until the hearth is of the final shape. Molten tar is brushed along the side walls where the hearth impinges, further to bind the bottom to the sides. As this tar will burn out on heating, the hearth made in this manner must be made thicker than desired so that after this contraction it may be of the proper depth.

As soon as the desired contour is obtained, the hearth should be shaped along the walls and built up as high as possible on the sides. When this is done the furnace should be well cleaned and the roof set. On the tops of the wall brick, place a ring of thick mud containing a high proportion of silica sand so that when the roof is set this will squeeze out and make a perfect fit.

#### *Burning-in the Bottom*

A small wood fire is started in the furnace and allowed to burn slowly for several hours until the wall and roof brick become warm when it is increased gradually and kept going until the heat can be felt through on the bottom of the furnace shell. Coke then may be thrown in until the hearth is covered to a depth of about 5 or 6 inches. As soon as this is red, the electrodes may be lowered and the arc started. The power is placed on the lowest possible point and is brought gradually to the point where the roof and walls are glistening, but not running. The hearth then is held under this temperature for from

12 to 24 hours depending on the size of furnace and thickness of hearth. A 3-ton furnace with a hearth of from 6 to 8 inches in thickness will take almost 12 hours. A sharp pointed bar is inserted into the furnace at stated intervals and shoved into the hearth. This shows the progress of sintering, and as soon as the test shows finished, the current is thrown off, the furnace cleaned, and all is ready for the first heat of steel.

While a hearth made in this manner often proves satisfactory, it is certain that it is not high class workmanship. The point of greatest burning will be directly in the center under the arcs, and gradually will taper off to the side walls where the burning in the dead corners will be insignificant. Consequently, there will be a time when a bad hole will develop and the metal will force its way under this half burned mass with the result either that the entire hearth will come up, or the bottom will start to loosen and large chunks will tear free. The author has seen entire hearths come up and float on top of the metal requiring strenuous effort to save the furnace without allowing the metal to skull. A bottom set in the manner mentioned in a basic furnace is too risky and should not be allowed unless it is intended for a test to last for only a few weeks while basic operations can be tried out.

### *Second Method*

Ramming bottom in layers is slower than direct ramming, but gives better workmanship, and is not so likely to cause the trouble often encountered on the straight rammed hearth.

The procedure is similar to the foregoing in that the same general ideas are followed regarding bonding material, etc. For the first layer, the bricks are painted with tar, and the mixture rammed in about 1½ to 2 inches thick. The furnace is heated and coke added when the arc is struck and baking proceeds until this layer is com-

pletely fused. The current is shut off, the furnace cleaned, allowed to cool down, and another layer rammed into place. As the layers approach the finished shape the percentage of slag to magnesite is lowered and each layer has a longer period of sintering.

This method allows an inspection of each layer as it is placed, and insures a freedom of unburned spots. The main objection is the length of time necessary to complete the work, together with the fact that the bond

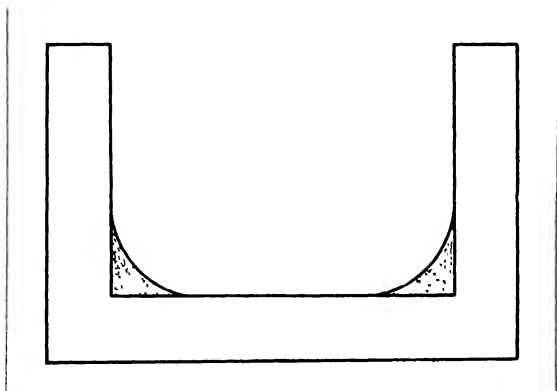


Fig. 8—Building Up the Dead Corners Preparatory to Burning in by Layers

between layers is none too secure. Trouble often is encountered from this as the metal may work down to this joint and result in forcing up an entire layer of the furnace hearth.

### *Third Method*

Gradually sintering in the refractory is the only entirely satisfactory method of making a hearth for the basic furnace, and while it is more costly and is a hot, and hard job, the energy and expense will be more than repaid by the absence of trouble when steel is produced.

By this method, a hearth is obtained which consists of one monolithic mass, truly burned, and capable of standing the temperatures of extremely high heats with no danger of coming up. To burn in a good hearth properly requires considerable skill and experience, and as this feature of furnace work is so important, considerable amplification on this subject will not be amiss.

If the bottom has been built flat, the first step will be to ram in sufficient magnesite and tar mixture to build up

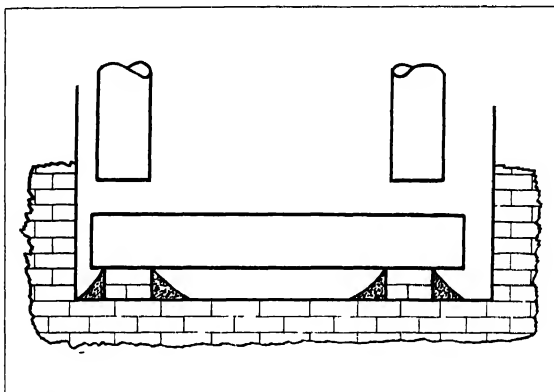


Fig. 9—Electrode Setup for Sintering in the Bottom

the dead corner as is shown in Fig. 8. This tends to give a slight start when burning is commenced, and aids in beginning the curved shape. If the hearth has been shaped of magnesite brick there will be no necessity of this and the electrode setup may be placed.

#### *Electrode Setup*

This electrode setup is intended as a neutral connection upon which the arc will be struck, and as it must stay in place until the hearth is finished the greatest care must be exercised to insure sufficient strength to outlast the

entire burning operation. The electrodes comprising this connection must be placed high enough up from the bottom brick to allow whatever depth of hearth is desired which will usually be from 5 to 8 inches. They will be set on magnesite brick as shown in Fig. 9, with the top brick slightly chipped so that there will be no danger of the round electrode tending to roll off. Around these brick enough magnesite mixed with sodium silicate is rammed so that there will be no danger whatsoever of the brick spalling away and allowing the setup to drop. The lengths of electrode will be such that about 8 or 9 inches

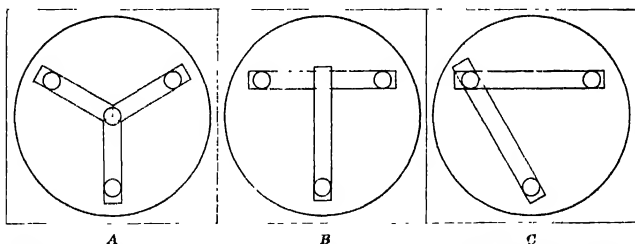


Fig. 10 A—Star Setup for Electrodes Used in Burning in the Bottom  
B—Electrode Setup for Larger Furnace  
C—Electrodes Placed in this Manner Are Strong

is allowed on the ends from where the arc will strike so that no trouble will be encountered with burning away during the operation.

The shape of such setups will depend upon the position of the furnace doors, and will be such that the greatest possible area of furnace bottom may be reached from the doors. Fig. 10 shows a star setup which is commonly used on the smaller size furnaces. The electrodes are chipped carefully so that a good fit is obtained at the joint, and a plug set as shown further to strengthen this connection. The plug may be set either on the top or bottom, but must be so fitted that when the setup is

finished it is extremely rigid, and does not move on shaking. The joint of the electrodes then is plastered carefully with carbon paste or electrode compound and allowed to set. This arrangement is suitable for furnaces up to 3 tons in size as it can be made easily, and of sufficient strength to withstand considerable abuse.

For larger furnaces where the electrode span is greater a more suitable arrangement is shown in *B* and *C*, Fig. 10. Both of these are strong, and do not require so much chipping, which is difficult on electrodes over 10 inches in diameter. The fittings of these electrodes may be done by an air gun and chisel which is an excellent method of obtaining a quick and tight fit. Carbon electrodes are much to be preferred over graphite for this setup due to their greater strength.

This neutral connection being placed, the next operation is the drying out of the furnace. If gas is available, it is preferred. A pipe may be inserted from each side of the furnace and a light flame used for the first 2 or 3 hours. By this time the roof will be warm to the hand, and steam will be issuing from the furnace vent holes. The flame may be raised gradually until the interior brickwork is at a dull red heat. If there is no gas, an oil torch may be used, or some arrangement which will not give too sharp a flame. Wood or coke may be used as a last resource, but are objectionable in that the furnace must be allowed to cool sufficiently for a man to get inside and clean out the ashes and unburned residue.

When the interior brick work is at a dull red, it is safe to assume that most of the moisture has been evaporated. This preliminary heating should not be forced, but should take from 8 to 12 hours, always remembering the old adage, "it is better to be safe than sorry."

### *Start the Arc*

The electrodes now may be lowered and the arc started. Current should be at the lowest figure which



will hold the arc steady. After several hours, the power gradually may be increased until the greater part of the refractory expansion has been taken up and the brick are at a red heat. As soon as the roof and walls begin to glisten it is probably time to begin making the hearth.

A small amount of sample mixture containing about one of finely ground slag to five or six of grain magnesite is made up and a small pile placed on each door sill. After about 15 minutes this may be examined and if thoroughly sintered, the furnace is hot enough to start operations. A few shovels of slag are dusted over the bottom brick, and melted sufficiently to allow the molten mass to run into any open cracks. This also makes the bond between the magnesite and the brick. As soon as this molten condition is obtained the first magnesite mixture is thrown in with shovels, being distributed carefully over the entire hearth to a depth of not over  $\frac{1}{2}$  inch.

Small samples may be taken intermittently by a special tool made for this purpose. This tool is shovel shaped of a size about 3 inches long, 2 inches wide, and  $\frac{1}{2}$  inch thick, with a sharpened end, and a handle at least 10 feet long. The method of taking such a test is to poke this chisel point into the bottom mass and withdraw a small quantity from several different parts of the furnace. These tests should all show a perfect sintered condition before the next addition.

#### *Regulating the Sintering*

If any portion of the hearth seems to be running badly, it means that the proportion of slag is too high, and it should immediately be touched up with a small amount of pure magnesite until the proper sintered appearance is obtained. If any part refuses to sinter it must be lightly touched up with a small amount of the slag. As soon as one layer is finished, it is time to add the next, and this is continued until the hearth is nearly finished. This is the most critical time in hearth building. The bottom is

assuming a finished appearance, and the men are becoming tired out. The tendency at this point is to try to rush operations and carelessness must be avoided or trouble will be the result when steel is being made.

When the center of the hearth has attained the desired depth, the side walls gradually may be built to shape. A spoon is used so that the refractory may be placed exactly where desired without any chance of droppings further raising the bottom. Often it is helpful to wet this mixture slightly which aids in holding it in place along the sides. As soon as the hearth is completed it is given a light dusting of slag and heating continued until this has melted thoroughly and run into any small fissures or openings, when the current may be shut off and the hearth is completed.

The electrodes are quickly knocked out of place and pulled from the furnace, and any spots under them carefully filled with magnesite, well rabbled into place. If the hearth has been well made, it should ring when a bar is thrust against it, and should be as hard as a wall of concrete. The greatest of care must be exercised during this burning, to avoid any undue overheating, tending to make either the roof or walls run, as this silicate running on to the hearth will prove a point of weakness.

#### *Care Must Be Exercised*

One of the greatest sources of trouble in burning in a hearth is caused by a tendency to hurry. The result is that there will be points at different places in the hearth where the material has been only partly burned. The next layer probably will sinter well over this and will form a shelled spot, which to observation will look satisfactory, but upon any slight hole forming will result in an undermining often with disastrous results.

To make sure that there is no possibility of such an occurrence it is well to take frequent tests with the spoon

from various points in the hearth, and not to proceed with further building until sure that each layer is perfectly sintered.

Great diversity of opinion exists regarding the time necessary to set a hearth, and whether it is preferable to finish the job in one operation. The author has used over 25 hours on a 6-ton furnace, and later on the same equipment placed a hearth in 11 hours. Both hearths ran indefinitely, the first being removed to try acid operation

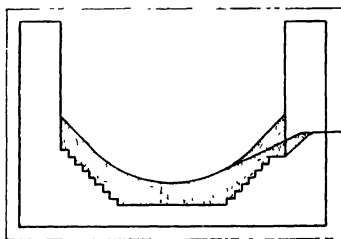


Fig 11—Finished Shape of Hearth Made by Burning in a Stepped Brick Bottom

after running over 2000 heats. The second was placed in operation in 1921 and is still in good condition, in a shop operating 6 heats per day. The variation in time was due to difference in experience of helpers, slightly changed power conditions, different magnesite, and such causes. Making a hearth is similar to making a heat of steel, in that the greater the care the better the product.

The practice of finishing the hearth in one operation, is preferred and a great saving in time and power is affected by such practice, due to the fact that there is no cooling down of the furnace over night. Further a hearth made in one operation is better than one allowed to cool over night for the reason that there is no possibility of a seam occurring between layers. Many successful opera-

tors allow their furnace to remain shut down over night, and they have had good success in hearth building.

Fig. 11 shows the appearance of the finished hearth made by burning on a stepped brick bottom.

### *The First Heat*

Often after burning in a bottom it is customary to make the first melt a *wash heat*, little care being used to make any particular quality of metal, the main idea being to assist in setting the bottom, and to remove any loose material. Often, the bottom electrode setup becomes frozen in and it is impossible to remove it without this wash heat.

Under ordinary circumstances it is not necessary to make such a heat, but the furnace may be operated directly on steel for whatever purpose desired. If there is no particular hurry to make finished material, it is excellent practice to set the bottom by such a heat as is mentioned. The best possible type of a melt for such purpose is one of *synthetic* iron. Any grade of steel scrap is thrown in the furnace with sufficient carbon to raise this element up to about 3 per cent. After melting, a heavy lime slag is made up, which is splashed as high up on the walls as is possible. Such a heat closes any small cavities in the hearth, aids in bringing up the side walls, and thoroughly removes any foreign matter from the furnace. The iron produced if poured into small size pigs is later used for recarbonizing.

While on the subject of basic bottom making, it might be well to mention certain machines built to throw patching material automatically into the furnace. Such equipment does not find wide use in small installations such as are found in casting shops, but is important in the larger installations. A smaller counterpart of the standard machine may be made and gives excellent service in patching the side walls, especially around the roof ring.

*Using a Cement Gun*

One type of machine is the standard cement gun which has found wide use for placing cement into position. This comes in different sizes, the smallest being handy for electric furnace use. Another type of machine is intended for open hearth use where large quantities of patching material are used at one time. The principle of these machines is a stream of air being forced through a hose, the suction produced carrying the patching material with it. Naturally all that is needed is to point the nozzle at the desired point, turn on the motor, and as long as the tank remains full of refractory the machine will place it.

*Spouts and Door Linings*

Due to charging and pouring operations, the wear around the doors is severe and some method must be devised to keep these important points in condition. The pouring spout, and around the jambs is made of magnesite, but unlike the hearth proper, is never under sufficient heat properly to sinter this refractory in place. These places must be kept up by ramming refractory mixtures into place, and due to the lack of cohesiveness of magnesite a natural binder must be used. The best the writer knows for such a purpose is sodium silicate.

After pouring, any slag or small metal skulls are removed from the spout with a sharp pointed bar, and a mixture of magnesite and sodium silicate rammed into place. This mixture is made of such a consistency as to be just moist to the touch, and after air setting for about an hour, makes a hard and durable refractory. The same mixture may be used around the door jambs with excellent success.

Of late years extensive experiments have been conducted with refractories which will stand better the rough usage of the basic furnace than the ordinary magnesite and silica brick. The main objection to silica

brick above the slag line is its short life. With the basic slags used, a heavy lime vapor always is present in the furnace which at the high temperatures attained rapidly attacks the acid silica brick, especially at the points opposite each arc. Here the arc often is deflected against the wall causing the brick to assume a pasty condition. Now when the heavy lime slag is splashed upon this acid mass, rapid disintegration follows, the result being a wall so cut in at these points that a relining, with its loss of time and ton-

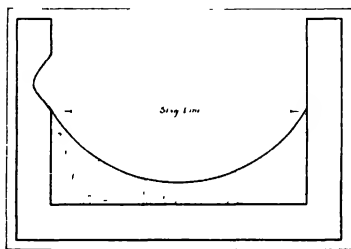


Fig. 12—Silica Brick Used in Basic Operation is Attacked by Lime Vapors at the Slag Line

nage, is mandatory. Such a condition is shown in Fig. 12.

This fault being common to all silica brick used in lining basic furnaces, many methods have been advocated to eliminate this objectionable feature. One of these is to use magnesite brick for the entire wall. Naturally this overcomes any slagging tendency, but again brings another objectionable feature, that of spalling. Magnesite brick lacks strength under changing temperature and this is evidenced by heavy spalling and flaking of the brick surface. Under standard conditions of operation this is so severe that the extra life obtained over silica brick is not sufficient to make up for the increased cost.

Such materials as mica schist, special alumina bricks, and refractories containing zirconium have been advocated

as a cure for these troubles, but none have been thoroughly satisfactory. Carborundum brick have proved satisfactory, as have brick made of the same quality of magnesite as goes into the standard product, but surrounded by a thin sheet metal case. When placed in the furnace this metal melts on the outer few inches and binds the wall together in one compact mass. The steel shell further prevents spalling or flaking by acting as a support to the magnesite itself. The added cost of these brick will be

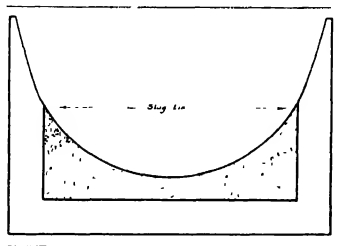


Fig 13--Brick for Basic Linings Occasionally Fail in This Form Leaving Short Length Near the Slag Line

more than made up by increased life of walls and avoidance of shutdowns. When a wall laid with these brick does fail, it has the appearance of that shown in Fig. 13. When the furnace is relined these short pieces of brick from the top of the wall may be used to patch lower down with the elimination of any waste.

Carborundum made into brick form lately has found wide use for certain purposes, but due to its high cost generally is not used for entire walls. This compound is negative to a basic slag, but is corroded and dissolved by hot metal. Therefore, it must be used in the furnace where it is removed from any splashes of metal, and for such uses where its cost may be reconciled. It has found a steady increase for such purposes as a small patch directly be-

hind each electrode where the arc strikes, being placed just high enough to be out of the reach of any metallic splashes, for arches, and for the skew back ring of the roof.

Carborundum brick have been used in many instances for entire roofs, but due to their ability to conduct current it has been necessary also to use some non-conducting brick which give way first and destroy part of the efficiency of the carborundum.

Appendix tables, 1, 2 and 3 give the logs on burning in bottoms on basic furnaces.



## V

### LINING THE ACID FURNACE

**B**UILDING an acid-lined furnace involves procedure similar to that followed for basic units. The lower courses will be of fire brick, set in the same manner, and the side walls consist of silica brick alone. The same features of allowing for expansion, etc., are followed, and the two methods of either stepping up the hearth brick, or laying flat will be optional. This point is not of such great importance as in basic operation, but depends entirely upon what method will be pursued in setting the hearth. If the hearth is to be rammed and baked, there is no necessity of stepping off the brick; if the hearth is to be burned, stepping the brick will give similar economies to those encountered on the basic hearth.

The deciding point in brick laying therefore, will follow the choice of bottom making. Acid refractories have a much lower melting point than magnesite, and may be bonded with excellent acid cements. Consequently, the necessity of actually burning in bit by bit is not essential to a good hearth, although it is common practice among a large number of furnace men. The rammed hearth is just as good and is much more economical, besides being an easier job, and one in which a better shaped hearth may be attained.

#### *The Sintered Hearth*

Assuming that this method is to be followed, the brick are offset as described under basic practice. The furnace is dried out, and the electrodes set up on the bottom brick in any manner desired. The depth of hearth desired will determine to what height they are elevated by silica brick. The current is turned on until the furnace is sufficiently hot to sinter in the refractory, when building commences. Any good grade of silica sand is

satisfactory, finely ground fire clay being used as a binder similarly to open hearth slag with magnesite. The general mixture used approximates 12 to 15 parts of sand to one of clay, but this requires constant adjustment for the proper degree of sintering.

Care must be exercised to prevent the furnace from becoming too hot or the furnace brick will run badly and contaminate the hearth with burned silicate which has poor refractory qualities.

### *The Rammed Hearth*

Ramming an acid bottom is rapidly assuming favor over the old burning process. This, in all probability, has been due to the labor entailed being so much easier, the burning of a bottom being truly a heart breaking operation. Too, ramming is so much cheaper and quicker. The real point is of course the service obtainable under operation conditions, and it must be admitted that the rammed hearth for acid steel is giving just as good results as one burned in.

In the preparation of such a hearth, there is no necessity of stepping up the brick, and consequently the bottom brick are laid flat. The usual procedure of laying two courses of clay brick against the shell, followed by two of silica is customary. In laying these silica brick, allowance must be made for expansion or future heating will bulge the hearth. As soon as the furnace has been completely bricked, the hearth is given a coating of some binder to cement the bottom of the hearth to the bottom brick.

There are many satisfactory cements or mixtures for this purpose. Glutrin, sodium silicate, and a number of specially prepared high temperature resisting cements all have acceptable properties, that of air hardening and setting with a perfect bond. All have good refractory characteristics, and may be used with success. About

three or four hundred pounds of sand (see Table XII) is mixed to a moist consistency with one of these binders. A patch along one side of the hearth then is smeared with the cement and while still moist, the sand is shoveled in and rammed well. This is continued until the entire hearth is so covered. As the hearth rises up on the walls they also are painted to insure the sand holding firmly to the brick.

The sand mixture thus is raised gradually until a hearth of the desired depth and shape is formed. Air rammers are used and it must be remembered that the hearth cannot be rammed too hard. The entire hearth should be as hard as a brick before the next layer is added.

Table XII  
BOTTOM SAND ANALYSIS

Locality	Silica	Percentage	
		Oxides	Lime
Alabama	87.80	4.90	4.00
Illinois	95.00	1.48	3.08
New York	97.78	1.73	.61
California	80.00	12.15	2.05
California	86.26	8.57	1.46
Chicago	88.89	5.67	.99
New Orleans	94.30	4.20	1.00
Colorado	83.30	13.40	3.25

and it certainly pays to devote plenty of time to this important operation. Should it be necessary for any reason to stop, allowing a layer to air set, the entire surface must be painted with cement before another layer is put in.

While the sand may be mixed by hand using shovels, it is much preferable to use a sand mixer or muller if this is available. This not only is quicker and easier, but gives a better mix to the material. After the hearth is rammed, the furnace should be tilted in each direction, and the mixture rammed up as high along the back and front wall as possible. When burned into place this furnishes a wonderful aid not only in keeping the furnace

free of hanging scrap, but gives a much prolonged life to the side wall refractories.

### *The Conducting Hearth*

Al. Bryant, Pittsburgh, agrees with the author that burned-in bottoms are the better, but in the conducting hearth type furnace this is not possible because the bottom must be laid so as to be a good electrical conductor. He states that this is accomplished by mixing steel slugs or punchings thoroughly with the batches before ramming them in. No bricks are set on the bottom plate, but the entire depth of bottom is rammed. It all depends how much one can spend on the bottom whether pure magnesite or the mixture of magnesite and a dolomite product is employed. The latter may be run to a high percentage if a cheaper bottom is desired, but straight magnesite gives the best results. Copper is a good conductor, while graphite is not quite so good. Then follow amorphous carbon, and steel punchings used to carry the current. The conductivity gradually diminishes from the copper plate to the hearth proper. The reduced conductance gives rise to greater resistance to the passage of current and the current is dissipated in heat which adds itself to the bottom of the charge. The bottom also is a fairly good conductor so that a contact is made between the third phase hooked on the bottom at the copper plate and the other two phases hooked to the two electrodes. If a bottom of this nature were burned in, all the steel in the bottom mixture would melt and run to the lowest point, the center. There would be increased conductance at the center and increased resistance at the other points of the bottom so that all the current would pinch at the center and overheat that point. Were a bottom laid thus heating would be irregular.

According to Mr. Bryant the batches for ramming must be heated separately before mixing. The magnesite

and dolomite product are preheated on a steel plate under which is a wood fire and the steel and basic slag are added and stirred in. The dry batch should be heated so that one cannot place the palm of his hand on the batch for more than the fraction of a second. The pitch is heated in a tar boiler and poured onto the dry batch and mixed thoroughly until the batch shows a little moistness from it. Batches must be made small, about 10 shovels full at a time and ramming must be done immediately while the batch is still hot. This is best done with air rammers. It takes some practice to tell whether the batch has the right amount of pitch. If it is too wet it will not ram and if it is too dry it will not ram and if it is too cold it will not ram.

#### *Drying the Hearth*

The hearth being rammed to shape in the manner described in the previous chapter, and the walls banked, the roof is set and the furnace is ready for drying. As there is no objection, under this method of bottom making, to contaminating the hearth, wood may be used for this drying operation. Wood is recommended as the greatest part of the heat obtained from a bed of hot coals will be thrown where most wanted, directly into the rammed sand. A small fire is started directly in the center of the hearth, and kept going until gradually a fair bed of coals is obtained. This generally takes 3 or 4 hours, when the roof and side walls will be thoroughly dried. The fire now may be increased rapidly until a bed of coals 6 or 8 inches thick is obtained, distributed evenly over the hearth, and up along the banks as high as possible.

This bed of fire is maintained until the bottom shell of the furnace begins to feel hot to the hand. On a 3-ton furnace this will take generally 10 to 12 hours, assuming that the depth of hearth is about 15 inches. Coke, in lumps about the size of your fist, then is shoveled in, being mixed with more wood. This procedure is followed

until a bed of red hot coke not less than 4 inches thick is obtained. By this time the furnace shell will be so hot around the sides and underneath that it is almost impossible to hold the hand against the steel plate. This means that absolutely all moisture has been dissipated, and it is safe to proceed with the actual baking.

As silica is readily reduced by coke at high temperatures, the heating must be kept below the point of reduction or the result will be a hearth containing spots of partially reduced sand which will melt out rapidly under the influence of steel, and absolutely ruin the hearth, or at the least form badly pitted spots. All that is necessary is to keep this bed of coke at a good white heat. If there is any tendency to overheat, the current may be shut off and the furnace allowed to soak. Watch the edge of the jamb bricks and at the first sign of glistening, turn off the power until the brick cease shining.

Ordinarily when the power is first turned on it is held for about two hours, or until the bed of coke is dazzling white. The procedure then will become intermittent, shutting down for about 15 minutes, then under power for about the same time. This period of heating will take from 6 to 8 hours, when the hearth will be baked sufficiently to be ready for steel. In Appendix Tables 4, 5, 6 and 7 are logs of burning in acid bottoms.

### *The First Heat*

The power then is turned off and the coke and ashes raked out by tilting the furnace and using rabble bars. If possible a heat should be made immediately that the hearth may be finally set before cooling down. The first heat should carry a large volume of slag which should be splashed heavily on the walls to tend to bind in the rammed banks.

The spouts and portions of the walls and bottom around the doors under acid practice are repaired in a

manner similar to that described under basic practice, with the exception that sand is used instead of magnesite. The sand is made into a heavy mud and plastered to shape with a trowel. Any good binder is satisfactory for this purpose sodium silicate being preferable due to its cheapness, and ability to set in a few minutes. Ordinarily, the spout will have to be cleaned out every few heats, as slag gradually builds it up to a point where the metal will not drain completely. It may be placed in shape and dried out for half an hour with a light wood fire when it is again ready for steel.

In acid furnaces rammed linings are used to some extent, especially in furnaces up to 2 tons in size. The exponents of this practice claim cheapness, and ability to patch quickly as the main assets. The writer has tried this method several times, using different patented cements, the test being made to prove the manufacturers claims. While the rammed lining is satisfactory, it is not cheaper than one of brick. It will not give the same length of service. It takes longer to lay, and must be more thoroughly dried out than a lining of silica brick before going under the arc. Further, it is more likely to crack and shell badly, often failing when least expected.

It is advisable, when shipments of brick are delayed or where the operations are so intermittent that it is too costly to keep a stock of brick shapes on hand to resort to a rammed lining. For furnaces under 1 ton in size, where operations are continuous or nearly so, a rammed lining will give excellent service for the reason that it becomes coated with slag and is never allowed to cool down enough to crack or spall off when reheated.

The method of building a side wall is similar to making the hearth. A wooden form is constructed, usually in sections, of the proper shape and size to give the thickness of wall desired. This is placed in the furnace and the refractory material rammed between this

form and the furnace shell. The mixture is made exactly like that used for the bottom, and is well rammed into place, a little at a time. The same precautions must be observed here as for the hearth, that certain binders will work only under steady operations, while others are satisfactory under varying practice.

After the entire wall has been built to shape, it is allowed to air set for several hours, when the form is removed and the furnace thoroughly dried out. In some

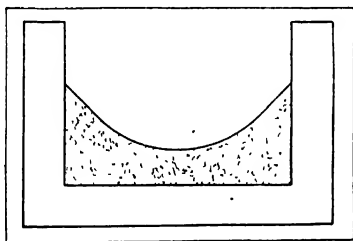


Fig. 14—Deep Bowl Type Hearth is Conducive to Rapid Melting

cases a rough form is constructed which is allowed to remain in place, being burned out when the furnace is undergoing its drying operations.

A rammed wall may be strengthened by inserting gagers and ramming around them, but this must be watched carefully or the metal, due to its greater expansion will cause the refractory to crack.

### *Hearth Shapes Important*

Having noticed at various times that differences in speed and economy of operations were obtained with hearths of different shapes, a series of experiments were conducted to determine, if possible, exactly the results occurring from such differing conditions. Experiments on basic practice were made on a standard 6-ton Heroult



furnace, operating over a 24-hour period, and engaged in the manufacture of steel for castings, forging and rolling ingots.

The hearth as first put in was of the shape shown in Fig. 14 being 8 inches thick in the center, the walls being run up as high as possible. After carefully following results on this hearth we allowed the bottom to build up, by charging lime on the hearth, to the shape as shown in Fig. 15, with a depth of 12 inches in the center,

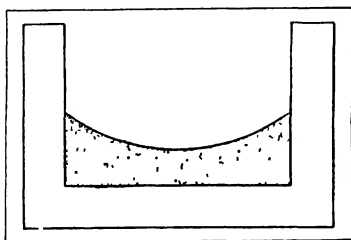


Fig. 15—Center Depression Built Up to Give Flat Type Hearth

the contour being rather shallow and flat. When the figures from this were sufficient to prove the results, we cut the hearth down to the shape shown in Fig. 16, by the judicious use of finely ground fluo spar. During the entire examination conditions of operation such as size of charge, character of scrap used, class of metal made, temperatures of pouring, etc., were kept as alike as possible.

The type of bottom illustrated in Fig. 14, held a charge of from  $6\frac{1}{2}$  to 7 tons without banking up the doors. Of all the shapes it melted down the most rapidly, probably due to the fact that the charge is more or less centered under the arcs, the walls being steep enough to allow for the automatic centering of the scrap as it melts down and falls into the bath.

It took this hearth longer to heat to the depth of metal under the arcs. For the same reason, refining was not as good as the type shown in Fig. 16, the effective slag area not being as large.

Trouble was experienced with the arcs cutting the banks opposite each electrode, due to the nearness of the wall to the point of the arc. The increased depth of this hearth required a greater length of electrode between the roof and the bath during melting down.

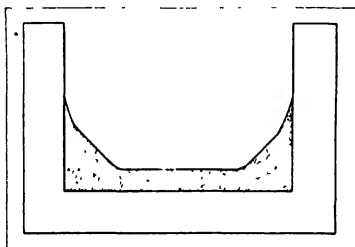


Fig 16 Type of Hearth Difficult to Maintain But Highly Efficient

For this reason, the holders must be fastened higher up on the electrode, which resulted in a greater surface exposed to the heat, and during refining, the air, which raised the electrode consumption.

The shallow hearth shown in Fig. 15 would hold only from  $5\frac{1}{2}$  to 6 tons of metal per charge, and proved of no value at all in view of the figures from the other two shapes. It took greater power, more time per ton, more electrode consumption in proportion, to turn out these smaller heats than it did with the larger tonnages on the other bottom.

The bottom of the type shown in Fig. 16 proved to be the best shape for the existing conditions, the only difficulty being to keep it to shape, the tendency being to build up to the shallow hearth. This was overcome

by sand and fluor spar and finally it was found possible to hold its shape more easily. While this type bottom did not melt as fast as the one first noted, the time per ton was less, due to a shorter time of refining and superheating. No trouble was experienced with the side walls, and refining, due to the large slag area, was possible without extra trouble, down to as low as 0.005 per cent sulphur.

With the hearth of the type shown in Fig. 16, it was found possible to melt and pour 8 tons of metal, in the same time as would take for 6.5 tons of that illustrated in Fig. 14, or 5.5 tons in the one like Fig. 15. On this bottom many 8-ton heats for steel castings were made, using the two slag process, in as short a time as 3 hours 5 minutes from the time current was on until pouring.

Experiments similar to the foregoing were conducted for a furnace operating on the acid hearth, the equipment used being a standard 3-ton 'Lectromelt. This furnace is built to use an exceptionally thick hearth, the normal depth of refractory being about 18 inches for a rated charge.

The hearth was first placed in operation with a 15-inch refractory thickness, being constructed to carry 5-ton heats. The shape was as shown in Fig. 14, with the exception that the banks were built completely to the roof, giving a deep bowl effect. After several months' operation, the hearth was allowed to build up about 3 inches so that the doors had to be banked for oversize charges. This gave a flat hearth like that shown in Fig. 15. Data collected and analyzed gave us the following:

The time of melting, power, electrode consumption, etc., were similar on both hearths.

Labor required to poke in scrap was less on No. 1, Fig. 14, the steep banks causing the scrap to fall in of its own initiative.

Roofs did not give quite as long a life with hearth

No. 2, Fig. 15, due probably to the fact that the distance from bath to roof was less than on No. 1.

Time of charging was greater on No. 2, Fig. 15.

Refining and superheating was superior and quicker on No. 1 on account of a smaller area of bath exposed with its attendant greater radiation loss. This also required a smaller volume of slag to act as a heat conserving blanket, giving a slight favor in power consumption.

From these data, the fact was accepted that on acid operations a deep, bowl-shaped hearth is superior to the flat hearth. Later operation figures have proved this point, and in addition have shown a more favorable power consumption. Such a hearth is easy to keep in condition, and offers a minimum of trouble caused by electrodes digging or arcing against the walls.

Thickness of the side walls is another feature of furnace detail upon which a considerable difference of opinion exists. A few years ago the author was in charge of a new shop where a 6-ton Heroult furnace had been installed. In the first bricking up of the walls the standard of the U. S. Steel Corp., using 18-inch walls was followed. During the operation of the furnace, it was noted that the inside course of brick rapidly gave way opposite the arcs, allowing the upper tiers of brick to fall into the hearth. After this first 9 inches of brick was gone, the remainder gave an exceptionally good life.

With this phenomena in mind, experiments were made over an extensive period to determine what thickness of side wall was preferable under the operating conditions at this plant. The first series of tests covered 18-inch walls, the brick being laid in different ways.

In the first test, brick were laid absolutely dry, standard key silica brick being used, laid end to end. No particular expansion allowance was made, the brick being loosely laid in place. After the first two heats all expansion was taken up and the faces of the brick

had run together nicely binding the entire wall into one homogeneous mass.

The inside arch course over one door dropped on the heat No. 31. On heat No. 42, the inner course behind the rear electrode was burned through and the brick above it fell into the furnace. On heat No. 46, the entire inner course had failed, a great portion of the brick falling into the bath due to a loss of their foundation. Some of these brick were 4 to 5 inches thick. The remaining 9 inches of brick ran for 86 additional heats, until a hot spot developed on one wall necessitating a shut down for repairs. The total number of heats from this lining was 132 or 858 tons of metal.

On the second test, brick were laid in the same manner with the exception that the two courses were cemented together using a stiff mud made of fire clay and sodium silicate. The entire first course held in place a little longer going in over a period from the 27 to 51 heats. The arches held in places extremely well only dropping after the jambs had fallen. The total life of the complete lining was 119 heats or 774 tons.

On the third heat magnesite brick were used opposite each arc, a patch about 18 inches square being used. The inside course lasted for 68 heats, the first failure occurring at the arches and jambs due to burning away. The magnesite held up well, but as the silica brick surrounding them burned away, they spalled enough to keep the wall even. The entire lining lasted for 182 heats or 1183 tons.

Carborundum brick were used opposite each arc for the inner course on the fourth test. These were laid on the magnesite brick and silica brick run from above them to the roof. When the inner course of silica brick had been completely eaten through, the magnesite underneath had been about 50 per cent consumed, while the carborundum brick had eaten away approximately 1

inch. In this light the apparent ratio of the resistance of the three classes of brick would be carborundum, 1, magnesite, 5, and silica, 9. However, as soon as the magnesite course supporting the carborundum brick had failed, these brick were lost, due to falling in the bath and slagging away, and much of their value was needlessly lost. The total life of this wall was 170 heats or 1105 tons.

The next series of tests covered walls 9 inches thick, using silica brick straight, silica brick with magnesite patch opposite the electrodes, carborundum patch, etc. Lives varying from 75 to 125 were obtained from such walls, those using the carborundum patch giving the longest service.

From our data we derived the fact that a 9-inch wall gave greater life than an 18-inch section, and that a small patch of highly refractory brick opposite the weakest point, *i. e.*, where the arc impinged on the refractory, increased the length of life considerably.

A similar series of experiments was conducted by another firm covering a comparison between silica brick and a metal covered magnesite brick. It was found that the latter not only gave a much longer life, and proved cheaper, but that the quality of the product was bettered by the elimination of silica combining with the basic slags, and destroying their effectiveness. A stronger lime slag was obtained with its attendant better desulphurizing qualities.

On acid furnaces, the thickness of side walls is not so important as the banks are kept up and the life of the brick is great. Such walls require only a small amount of patching periodically, and usually only on the two or three upper courses under the roof ring. On acid lining, several inches of some high heat insulator between the bricks and the shell increases the life. Any increased burning of the face of the bricks, due to the higher tem-

peratures and decrease of radiation easily may be overcome by throwing the patching material up against the walls. Such heat insulators as asbestos, diatomaceous earth, and several patent compounds prove to be thoroughly satisfactory for this purpose.

### *Care of Electrodes*

In electric furnace work, the consumption and cost of electrodes is an important item. Whether carbon or graphite is used, an attempt should be made to obtain as near 100 per cent service from each pound as is possible. The greatest loss in the effective consumption of electrodes is caused by undue oxidation, which is especially troublesome in shops making intermittent heats. After the last heat of the day has been poured, the electrodes are in a highly heated condition for a length of approximately 4 feet. This red hot carbon, when exposed to the air over night, is heavily oxidized, a large ash  $1\frac{1}{2}$  inch thick often scaling off next day. This loss is extremely hard to prevent, but certain steps may be made to lessen its effect.

When the furnace is shut down over night two methods of handling the electrodes may be followed. They may be raised as high as possible or lowered into the hot furnace. Exponents of both methods will be found. The National Carbon Co. in a handbook on electrode care and operation, advocates raising them out of the furnace as high as possible, explaining the action as follows:

Various attempts have been made to prevent this destructive oxidation—such as the use of nonburning paints or asbestos coatings on the electrode, or by cooling with a salt water spray immediately after the last heat of the day. However, the most practical means of combating this feature seems to be that of raising the electrodes as high as possible out of the furnace and luting up the clearance between the roof glands and electrodes with fire clay. This prevents the heat of the furnace from passing up and around the electrodes, and they will cool rapidly in the air with little oxidation. When running on one

shift a day, this method has resulted in a saving of about 20 per cent in electrode consumption.

It has not proved advisable to lower the electrodes into the furnace and attempt to obtain a reducing atmosphere by throwing in a little coal and stopping out the air. Air will leak in through cracks in the fire clay and between the brick in the roof and walls as the furnace cools and contracts, and the heat of the furnace keeps the electrodes up to oxidizing temperatures for a long time.

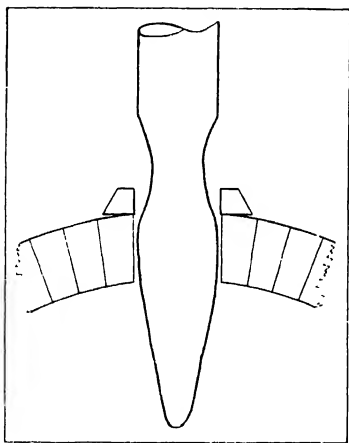


Fig 17—Rapid Burning Results in Spindling Leaving a Stub Which Quickly Is Broken

The writer has tried both of the foregoing methods thoroughly to determine, if possible, which is superior. It was found that as regards the loss in weight, both were about equal in most cases, but with furnaces having close fitting doors, the balance was in favor of lowering the electrodes into the furnace, due to the fact that a certain amount of heat thus was conserved. The practice in most shops is to charge as soon as the heat is poured which makes the raising of the carbons mandatory.



*Loss By Burning*

Another great loss is caused by undue burning above the roof glands, or *spindling* as it is commonly known. When the heat first melts down, the electrodes dig low into the furnace and heat so that when the height of the

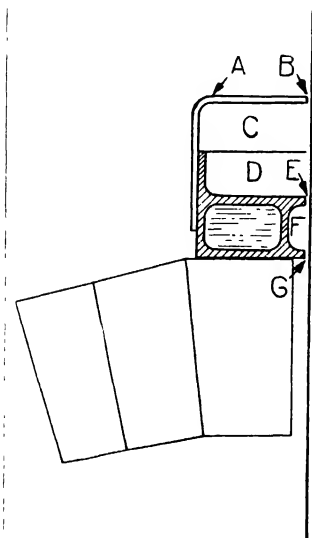


FIG. 18

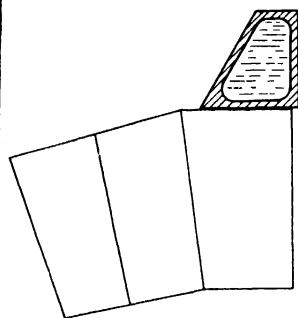


FIG. 19

Fig. 18 Special, Water-Cooled Gland Designed to Reduce Burning of Electrodes at the Point of Entry to the Furnace

Fig. 19 -- Water-Cooled Ring Constructed to Lower Temperature of Electrode

bath rises, there is about a foot of red hot electrode exposed to the air. Then the hot gases rising around the electrode from the roof ports keep this portion at a high temperature. The result is a rapid burning as shown in Fig. 17 with the result that the electrode is weakened

later causing the stub to break off. The loss in effective carbon from this cause is considerable and many methods have been devised to combat it.

Paints and coverings all have proved to be unsuccessful and much experimenting has been done along the lines of more effective roof glands. A roof gland is a water

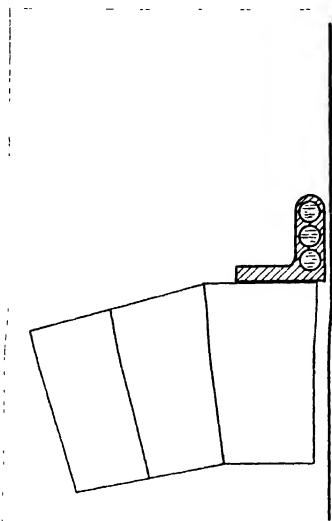


Fig. 20—Electrode Ring With Multiple Ducts for Conducting the Cooling Water

cooled ring surrounding the electrode where it enters the roof, the clearance between the ring and the electrode being as small as possible. The hot gases as they rise must pass through this small aperture, the attempt being to cool them down to a point where they will not ignite when entering the air. Figs. 18, 19 and 20 show different methods of applying this cooling principle.

The ring shown in Fig. 18 is a patent gland designed by the Electric Furnace Construction Co., Philadelphia, makers of the Greaves-Etchell type furnace. Fig. 20 is that used on the 'Lectromelt furnace made by the Pittsburgh Electric Furnace Corp., Pittsburgh, and Fig. 19 is the type of ring used on the Heroult furnace. In the older methods, straight water cooling was the only means attempted to lower the burning of this gas, while in newer types the rings are used to lower the velocity and temperature of the gas by permitting an expansion.

### *Principles Explained*

The principal of the device shown in Fig. 18 is as follows: The superheated gas with a high velocity enters the economizer at *G*. Here the first expansion is allowed, together with the first cooling operation. The large area, *F*, permits this gas to expand, losing its velocity, with the result that the period of water cooling is greatly increased. The semicooled gas then passes through the small clearance into the large chamber, *D*, where the expansion is such as practically to eliminate any velocity. Further cooling is here made possible. The gas then rises through a fine wire screen into another expansion chamber, *C*, where the last vestige of velocity is removed, the cooled gases gradually working their way out of the cover, *A*, at the opening, *B*.

Another reason for undue burning is the poor contact at the electrode joints, causing resistance to the flow of the current. Naturally, this heats the spot and the result is a red hot patch from 1 to 4 inches in diameter, depending on the lack of contact. As soon as this point burns away slightly, a clearance is formed, and a small arc is drawn. If too severe, the electrode nipple will be cut cleanly off allowing the bottom electrode to drop in the bath. Whoever has had to get up on a hot furnace and try to pull out an entire stub, broken off even with the

roof, knows the labor, loss, and delay of such an accident. The remedy is to maintain tight joints.

The vibration of the furnace always tends to loosen a joint and they should be tightened after every heat. The best way to do this is to obtain a standard chain pipe wrench about 25 inches long, and have a double length chain placed on. With this simple instrument an electrode may be tightened in about 5 seconds, and made so tight that there is no possibility of a bad joint. In mak-

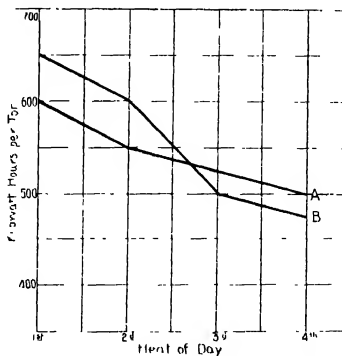


Fig. 21—Power Consumption of Three-Ton Acid-Lined Furnace Over a Period of One Year—Curve A Was Developed from Oversize Heats and B from Rated Charges

ing joints, plenty of electrode compound should be used so that when the joint finally is tightened the compound will ooze out, filling all microscopic cracks or openings.

The greatest care always should be used to avoid any careless operation which will result in electrode breakage. When the furnace is being charged, the electrodes should be raised well up out of the line of scrap so that there is no danger of a piece being thrown against the tip where weakness is greatest. When the scrap is melting and falling in, it is safe to raise the electrodes and poke in the

metal around them until a clear pool is formed. This avoids any chance of a body of scrap falling against and breaking an electrode. The automatic regulators always must be watched to prevent any trouble causing *racing* which is likely to cause an electrode to break off by allowing it to strike heavily against the charge.

### *Economical Operation*

The size of heats which should be made furnishes another point upon which there is considerable difference

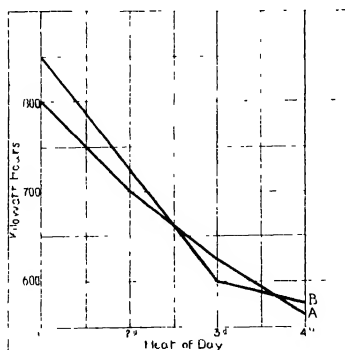


Fig. 22—Power Consumption of a Six-Ton Basic Lined Furnace—Curve A Was Plotted from Heats Running Not More Than 1000 Pounds Over Rated Capacity and B from Much Larger Heats

of opinion. When a 3-ton furnace is built, it always is constructed so that an overload of 100 per cent may be had if necessary. This leads to the production of oversize heats, charges of from 4 to 5 tons being the standard. This practice is similar on all sizes and types of furnace, the idea being that an oversize heat is a great deal more economical to make than a standard heat.

While in general it is desirable to run larger heats

due to the larger tonnage, proportionally less operating time, etc., it does not always follow that this practice is the most economical. Other features should be considered such as tied up floor space, rapid flask turnover, size of equipment, etc., all of which favor smaller heats.

The main point at issue is the difference in power per ton necessary, and the consequent difference in conversion costs, of the two methods.

Some light may be thrown on this subject by an examination of the two curves covering both acid and basic operations as shown in Fig. 21 and 22. Fig. 21 covers the record of one year's operation of a standard 3-ton 'Lectromelt furnace, operating on the acid hearth, and producing steel for medium size steel castings. Operations usually covered three heats per day steadily, although there were days when four were made, and many days when only two heats were poured. The work was as is found in any jobbing shop, the size of the work to be poured generally determining the size of heat necessary. On the larger heats the temperature of the metal was less than on the standard size heats, due to the larger castings being poured with metal as cold as was consistent with safety. Consequently the figures tend to favor the oversize heat slightly, when viewed from this angle.

Curve A, is that developed from oversize heats, those running from 7000 pounds up. Curve B shows figures obtained on heats under this figure. These curves show strong superiority for the large heat on the first two heats of the day, but favor the small heat for continuous operations. This is probably due to the time necessary for charging, the shorter time necessary for the smaller heat being sufficient to eliminate a great amount of the lost heat from radiation.

Fig. 22 covers the operation of a 6-ton Heroult furnace over a two-year period, using the basic process.

making steel for castings and high grade ingots, the operation being over the 24-hour period. Curve *A* is developed from heats of under  $6\frac{1}{2}$  tons, while *B* covers the larger sizes. The difference on the basic process does not appear to be so marked as on the acid hearth, probably due to the fact that the amount of heat necessary for the slags tends to stabilize any small melting differences.

Other operators have reported results differing greatly from those given, some reporting savings of as great as 15 to 20 per cent by melting oversize heats. There is no question but that the larger heats are in the end slightly cheaper, as the proportional time is less on the heavy charges. Consequently, the wear and tear on the furnace roof and walls, and the electrodes and ladles is less which may prove to be a considerable item at the end of a year's operation.

Continuity of operations is most desirable in an electric furnace shop. The curves aptly show the great drop in power used as the number of heats produced rises. Therefore, it is better to make two heats every other day than to make one daily, if the other shop conditions will warrant such action.

## VI

### PURCHASING THE SCRAP AND CHARGING THE FURNACE

**A**N ELECTRIC furnace making steel in the foundry is different from the furnace making extremely high grade products, in that economy is a prime requisite. Therefore, it follows that every possible saving must be made, both in purchasing materials and in production operations.

As scrap metal for the furnace charge is the material most handled and used, certain set rules should be laid down for the procedure under which this item will pass from the preliminary order until it is charged into the furnace.

In purchasing scrap, certain differences will arise, due to the size of furnace, contemplated regularity of operation, choice of process, whether acid or basic, etc. These features will affect materially the character of scrap metal brought to the works. Scrap steel can be roughly classed under the following headings: Size, character and composition.

The size will depend upon two points, the size of the furnace and the intended operation. If the furnace is of 1-ton capacity, with doors 18 inches square, the metal must be such as can be handled easily in charging and small enough to be placed quickly in the furnace. The latter is particularly important if operation is continuous. Under such conditions, the greater percentage of scrap should consist of such classes of material as heavy borings, nuts, bolts, rivets, punchings, short-sheared steel, heavy forge flashings, ingot butts, etc. These are small in size and may be shoveled in the furnace in a short time.

The direct opposite to this would be a 6-ton furnace where only one or two heats are made in a day. Here



the doors are about 30 inches square, allowing a much larger size scrap and the time necessary to charge is not so important. Naturally, a cheaper grade of steel could be purchased, such material as structural butts, short pipe lengths, large plate shearings, mixed borings and turnings, miscellaneous forge flashings, etc. Such scrap usually is several dollars a ton less in price and while a longer time of charging would follow, there would still be a considerable saving in the final cost of the metal.

Regularity of operation is the deciding feature in the character of scrap purchased and depends also upon the process of operation. Where basic operation is used, it is permissible to allow a greater percentage of rust or dirt on the scrap, which is taken care of by the slag and has no ill effect upon the hearth. Dirty or heavily oxidized metal will corrode an acid hearth quickly unless carefully watched and allowances made for this oxide. This percentage of rust will depend upon the general character of the scrap, thin plate shearings having a much greater volume of oxide than ingot butts. This factor depends greatly upon the area of a unit of scrap. Consequently, for basic operations cheaper scrap is permissible allowing the use of bundled iron, old torn down machinery, boilers, etc.

### *Composition of Scrap*

Composition of scrap used is governed by the character of operation and the intended product and is handled under two main heads; the carbon percentage and that of phosphorus. If acid operation is to be used, it is mandatory to obtain a low phosphorus charge. Basic operations allow for phosphorus content considerably higher, due to the ability of this process partially to eliminate this undesired element. The amount of carbon desired in the product will control the charge to a great extent, as either raising or lowering the carbon in the bath is

to be avoided as far as possible. Consequently, if a soft steel is to be made, the charge will have to consist of such metal as will melt down sufficiently low, such classes of scrap as general structural, bolt and rivet stock, ingot butts from these products, old steel castings, etc., being particularly suitable. For higher carbon heats, the use of rail, old springs, etc., finds wide application.

Table XIII gives the various classes of scrap on

Table XIII  
SCRAP CLASSIFICATIONS, PRICES, AND ANALYSES  
Prices per gross ton, Chicago

Class	Price	Percentage				
		Carbon	Mang.	Sil.	Phos.	Sul
Heavy melting steel .....	\$13.00	0.15/0.30	0.60	0.10	0.05	0.05
Frogs, switches, cut .....	13.00	0.50/0.76	1.00	0.20	0.04	0.04
Shoveling steel .....	12.50	0.15/0.30	0.60	0.10	0.04	0.04
Low phosphorus melting ....	16.00	0.18/0.24	0.60	0.10	0.02	0.02
Forge flashings .....	8.50	0.10/0.20	0.50	0.10	0.04	0.04
Steel rails, cut .....	14.25	0.50/0.76	1.00	0.20	0.05	0.05
Axle turnings .....	9.00	0.38/0.52	0.80	0.20	0.04	0.04
Small structural .....	13.50	0.18/0.24	0.50	0.15	0.04	0.04
Steel axles, cut .....	11.00	0.38/0.52	0.80	0.24	0.05	0.05
Railroad wrought .....	14.00	0.05/0.15	0.40	0.10	0.12	0.01
Knuckles, couplers .....	14.50	0.55/0.70	0.70	0.40	0.06	0.05
Springs, coiled .....	15.50	0.95/1.05	0.40	0.20	0.03	0.03
Punchings, low phosphorus	13.00	0.10/0.24	0.60	0.10	0.02	0.02
Locomotive tires .....	12.50	0.50/0.85	0.75	0.35	0.05	0.05
Machine shop turnings .....	5.00	0.18/0.30	0.60	0.20	0.05	0.05
Light iron .....	5.00	0.05/0.15	0.40	0.10	0.12	0.05
Stampings .....	7.00	0.10/0.20	0.50	0.10	0.05	0.05

Manganese, silicon, phosphorus, and sulphur given as the maximum in each case.

the market, together with their comparative costs as of 1921. While the prices today have changed in general, the ratio between the classes still exists. The difference in price between such items as machine shop turnings, light iron, stampings, forge flashings and axle turnings on one hand and heavy melting steel, low phosphorus melting, punchings, etc., on the other, will be noted. The difference in this instance depends directly upon the case of handling.

Charging a heat of punchings in a 3-ton furnace

will take approximately 5 minutes per ton, while charging a similar size heat of light scrap will take probably three times as long or 15 minutes per ton. This extra time for two laborers at 30 cents per hour will amount to only 10 cents per ton, while the difference in cost of scrap is several dollars. Of course, one other point determines this difference in price, that is melting loss. The general scrap prices are based upon the supply and demand of the large open-hearth shops which cannot use light scrap due to its heavy oxidizing loss in their process. Under electric furnace operation, this is not a fact, the amount of loss for light scrap amounting to about 2 or 3 per cent above that of a chunky charge. The total saving per ton on using such scrap, therefore, is about \$2 per ton of hot metal.

#### *Select Scrap Carefully*

Scrap should not be purchased in an indiscriminate manner, but should be selected carefully after a thorough examination of all the prerequisites, as a few dollars difference in the price of the initial charge will make a decided change in the cost of the finished casting.

The scrap should be selected over as wide a range as possible, that proper selecting for each individual heat may be made, the idea being to have as well balanced a charge as is possible. Such a charge should be selected as to size of scrap and composition, the aim being to obtain one which will melt down to the desired point with a minimum of power and labor. A charge of loosely packed scrap will take a longer time to melt than one which is compact. In the same manner, any needless elimination of phosphorus by slagging off results in an added expense.

When the scrap metal comes into the yard it should be unloaded with a magnet and segregated as much as possible. All heavy pieces should be kept by themselves as should shoveling scrap, scrap which is either extra

clean or heavily oxidized. Pieces of irregular size which are hard to charge should be kept in one pile. There should be a further separation according to carbon content and in some cases when any high phosphorus scrap is received, it should be placed by itself. If this is done it is easy for the melter to make up his heat with a

Table XIV  
TYPICAL SCRAP MIXTURE

Varying methods of making up a charge with a carbon content ranging from 0.20 to 0.30 per cent, intended for soft steel castings, the heat to shape itself with a minimum of effort on the part of the furnace crew. Assume shop scrap to contain 0.25 per cent carbon, and to have a value of \$12.00 per ton. Other values taken from Table XIII.

Component parts	Percentage	Cost gross ton	Carbon percentage
No. 1			
Shop scrap .. . . .	15 00	\$ 1.80	0.038
Machine shop turnings . . . . .	20.00	1.00	0.050
Small structural .. . . .	50.00	6.75	0.120
Forge flashings .. . . .	15 00	1.28	0.025
	100.00	\$10.83	0.233
No. 2			
Shop scrap .. . . .	15.00	\$ 1.80	0.038
Shoveling steel .. . . .	15.00	1.88	0.038
Heavy melting steel .. . . .	15.00	1 95	0.038
Stampings .. . . .	30.00	2.10	0 045
Forge flashings .. . . .	25.00	2.12	0.038
	100.00	\$ 9.85	0.197
No. 3			
Shop scrap .. . . .	15.00	\$ 1.80	0.038
Axle turnings .. . . .	30.00	2.70	0.135
Light iron .. . . .	10.00	.50	0.005
Machine shop turnings .. . . .	20.00	1.00	0.040
Punchings .. . . .	25.00	3 26	0.045
	100.00	\$ 9.26	0.263

minimum of time and effort. When scrap is all piled in one heap, it often requires considerable time to pick it over to make a special heat.

### *Making Up the Charge*

In the preparation of the charge for any specific heat, several points should have consideration. The charge

must be of such chemical composition that when melted down it will give an analysis permitting finishing with a minimum of trouble. The sizes of the scrap must be chosen so as to enable the metal to be placed in one compact mass in the furnace. Further, such choice must be used as will insure a proper charge at the lowest

Table XV  
TYPICAL SCRAP CHARGE

Methods of making up a charge with carbon content of from 0.40 to 0.50 per cent, for medium hard steel castings.

Component parts	Percentage	Cost	Carbon
No. 1		gross ton	percentage
Coiled springs .....	30	\$ 4.65	0.300
Axle turnings .....	20	1.80	0.090
Forge flashings .....	35	2.97	0.052
Shop scrap .....	15	1.80	0.038
	100	\$11.22	0.480
No. 2			
Shop scrap .....	15	\$ 1.80	0.038
Knuckles .....	30	4.35	0.186
Locomotive tires .....	25	3.13	0.160
Machine shop turnings .....	30	1.50	0.072
	100	\$10.78	0.456
No. 3			
Steel rail .....	50	\$ 7.13	0.310
Heavy melting steel .....	10	1.30	0.022
Axle turnings .....	30	2.70	0.136
Stampings .....	10	.70	0.015
	100	\$11.83	0.483

possible cost for the metal. That innumerable combinations satisfy these points is admitted, but there is always the one best method for each set of conditions.

Tables XIV, XV and XVI show several varying methods of arranging the charges for certain specified heats.

Assuming that the different components of the charge have been decided upon, the procedure will be to place it in the furnace as shown in Fig. 23. The large, heavy chunks are spread over the entire hearth, especially in the direct path of the electrodes as they dig downward.

This delays their downward progress sufficiently to allow a small pool to form in the center of the hearth before the electrodes have reached this point. This is a safeguard against any tendency to arc against the bare hearth with its attendant bottom trouble. The interstices are filled with smaller scrap and care is observed to so arrange

Table XVI  
TYPICAL SCRAP CHARGES

Charges for extra hard steel running from approximately 0.70 to 0.80 per cent carbon.

Component parts	Percentage	Cost	Carbon
No. 1		gross ton	percentage
Coiled springs ....	45	\$ 7.00	0.450
Knuckles, couplers .....	35	5.10	0.217
Locomotive tires ....	20	2.50	0.130
	100	\$14.60	0.797
No. 2			
Steel rail .....	50	\$ 7.13	0.320
Axle turnings .....	40	3.60	0.180
Heavy melting steel ..	10	1.30	0.022
Carbon (coke) ... ..	11 lbs.	.05	0.260
	100	\$12.08	0.782
No. 3			
Heavy melting steel ..	20	\$ 2.60	0.044
Punchings .. ..	20	2.60	0.036
Axle turnings ... ..	30	2.70	0.135
Stampings .. ..	30	2.10	0.045
Carbon (coke) .. ..	22 lbs.	.11	0.520
	100	\$10.11	0.780

the upper layers of the charge that there is small likelihood of *bridging*.

The center core of the charge always should be of such a nature that as soon as it is slightly undermined by molten metal it will readily slip in and under the electrodes. The best class of scrap for this central portion is heavy turnings or similar small sized metal which does not tend to bond itself in one unbreakable mass.

#### Method of Charging

The method of charging this scrap will depend upon

the type of furnace being used and whether hand or machine charging is used. On such furnaces as the Heroult, Greene, Ludlum, etc., up to 6 tons in size, hand charging is the only possible method. If the furnace is on the floor level, the scrap must be placed in cans or boxes and lifted up by the crane. In either method, the carrier will be directly filled by the electric magnet and weighed before being charged, either on a platform scale or on a spring scale suspended from the crane. The

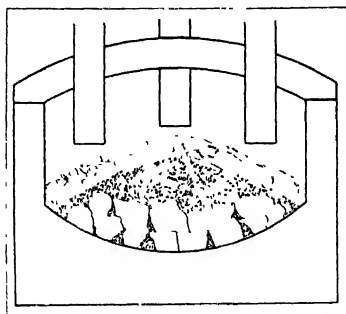


Fig. 23—Recommended Practice for Charging Scrap in Electric Furnace

scrap is dumped before the furnace doors and thrown in as quickly as possible. Extremely large chunks may be handled readily on a *peel* or long tong arrangement suspended from a swing crane, while such classes of metal as punchings, heavy turnings, nuts, rivets, etc., may be handled with shovels.

This hand charging is at the best a slow process and constitutes one of the greatest delays met with in electric furnace operation. While heavy scrap capable of being handled with shovels may be charged quickly, such classes of metal are to be had only in small lots and then usually

at a stiff premium. To overcome this loss of time many different methods have been advocated.

One furnace is constructed so that the roof may be tilted back, allowing the interior to be filled from the top. The manufacturers of this furnace advocate preheating the scrap in oil fired ovens, charging in drop bottom buckets and placing the scrap in position from above. While this method is good when considered from the standpoint of power saving, difficulty is encountered from the roofs. The constant exposure of a white hot refractory to the cold air when the roof is lifted may result in rapid deterioration of the brick, with a short roof and wall life.

#### *Gravity Charging*

Another type furnace has the main charging door directly in the rear of the furnace which makes possible the use of gravity in charging through the door, without raising the roof or otherwise exposing the refractories to cold air. This system makes use of a charging box, which is made of steel plate in the form of a long box, being approximately 24 inches square and about 8 feet long. This is mounted on wheels so arranged that when rolled up to the furnace, the front end of the charger is in line with the door opening. The front of the box is inserted in the door and latched into position. Rear end of the box is lifted by the crane, the furnace being tilted forward as the box rises. When the maximum furnace tilt is obtained, the rear of the box is about 10 or 12 feet from the floor at an angle of 45 degrees. Upon striking the box with a bar, the charge slides into the furnace.

Such a box will hold from 3000 to 5000 pounds of scrap, depending upon its character and takes approximately 10 minutes to charge. This is extremely fast work and naturally results in shortening the time between heats to a marked degree.

However, two disadvantages are encountered in this



method of charging. When this charge slides into the furnace, there is naturally a heavy impact. The scrap is thrown heavily upon striking and impinges against both the roof and upper side walls. The result is a gradual weakening of the refractory resulting in short life of both roof and wall. The most severe disadvantage is the building up of the hearth. When this charge of scrap strikes, it loosens all of the patching material on the banks which drops into the bottom of the furnace, with the result that the side walls tend to go down and the hearth rapidly builds up.

These buckets were used in a 3-ton installation under the author's supervision over a period of several months, but were discarded. In one particular instance, the acid hearth built up 8 inches in thickness during one week while the charging bucket was in use. Since discarding it, there has been no thickening of the hearth, this period being over 8 months. In every case where the bucket was used, the front part of the furnace roof gradually was knocked to pieces by the scrap striking against the brick, requiring constant patching to keep the roof in service.

In the furnaces of 10 tons in size, the standard charging machine, as used in open-hearth work, has found some use. In a shop in Buffalo where two 10-ton Heroult's are in service, the charging machine has been in use for some time. A charging machine also is used in a 6-ton Ludlum furnace operating in one of the prominent eastern shops. If the furnace is of such a size as to allow of the entrance of a charging bucket, this system of operation may be used, but it involves a heavy installation cost which the writer does not believe to be justified by the saving. Smaller furnaces naturally cannot consider such an arrangement.

#### *Movable Hearth Furnace*

One special installation is arranged so that the entire furnace hearth rolls on wheels, When the heat is poured,

the furnace is patched and the hearth run out from under the roof. The scrap, which has been weighed previously, is charged quickly with an electric magnet, the hearth being run back into place as soon as charging is completed. It is claimed that only 7 minutes is taken for thus charging a heat of 6 to 7 tons, from the time the hearth is run out until the current is on again. It seems as if the same objections would hold as for the system using the removable roof, namely rapid refractory disintegration. As most of the furnaces with the rolling hearth use magnesite brick for the entire wall, it would be imagined that the spalling loss would be severe.

Another company recently has placed on the market a furnace embodying a rather new principle. The installation consists of two complete furnaces mounted on an arrangement allowing of rotating the entire setup. One transformer and only one set of electrodes are used. One of the furnaces is charged and the heat melted. During this melting the other furnace is being charged. As soon as the first furnace has poured its steel, the electrodes are raised clear of the roof and the setup rotated so that the second furnace is in melting position. The electrodes are lowered and melting starts on the second unit. The total delay between heats is not over 5 minutes. Whether or not the added cost of equipment will counterbalance the elimination of delays remains to be seen.

## VII

### MAKING BASIC STEEL

**I**N MAKING basic steel several different methods are pursued, the choice depending upon the quality of the product desired, the choice of scrap, etc. The degree of both dephosphorizing and desulphurizing will tend to determine the choice of method to pursue. In basic operation the two main differences are the two-slag and the one-slag processes, which with many modifications for each give a large number of details to handle. Many melters tend to change the method of operation without considering important advantages to accrue therefrom. It is strongly advised to consider carefully any change in the procedure of melting or refining. If the present method of operation is satisfactory it is wise to continue in the same manner until it can be shown where it can be improved. If trouble is encountered ask for advice from some other man who has probably encountered the same difficulty and knows the proper move to checkmate your problem.

#### *The Two-Slag Method*

The two-slag method of manufacture probably is used more than any other basic practice. Two slags are used, the first being made under heavy oxidizing conditions and removed to eliminate some of the phosphorus. The second is made in a similar manner, but under a heavy reducing atmosphere, in which condition it has the ability to lower the sulphur content of the metal to a marked degree.

By far the best method to pursue in explaining the practice to follow will be to carry a heat through from beginning to end. Assume that a heat of steel is intended for a miscellaneous lot of castings, the intended analysis to be approximately as follows: Carbon, 0.22 to 0.28

per cent; manganese, 0.60 to 0.70 per cent; and phosphorus and sulphur below 0.05 per cent. This is the standard specification used to make steel for the American Society for Testing Materials *soft* classification and is the analysis generally used for all types of miscellaneous work.

The furnace is charged with a general assortment of low carbon scrap, the electrodes are lowered and the arc struck. The exact procedure to follow will depend upon what type of automatic regulator is in use. If a General Electric, the main switch is thrown in on high voltage and the electrodes are lowered with the push buttons until the arc is struck, when the furnace may be thrown from hand control to automatic. If a new type of Westinghouse regulator is used, an iron or steel bar is thrust in the furnace to make contact between the charge and the furnace shell. The switch is thrown on the high side and the regulator immediately thrown on automatic. The electrodes will lower themselves until contact is made, when movement ceases until the arc is broken.

At the start of a heat some melters prefer to operate the furnace on hand control for a few minutes until a steady arc is formed, when the automatic is placed in commission. This is an aid in avoiding electrode breakage as there is small likelihood of an electrode hitting hard against the charge. With the Westinghouse regulator, there is no danger of this for the wiring is so arranged that when the electrode touches the scrap, the electrode automatically ceases moving. Consequently, the furnace may be started directly on automatic. After about 5 minutes, when a slight pool has formed, the iron bar may be taken out of the door, as contact will be assured from this time.

The current is allowed to stay on until the charge has melted down. However, certain occurrences may cause a shutdown during melting.

Often the electrodes dig so low in the furnace that the holder rests against the roof gland. When this occurs, the electrodes must be loosened in the holder and the holder raised until there is sufficient length to allow running the remainder of the heat with no further delay from this trouble. This operation generally occurs about 20 or 30 minutes after the current is turned on and requires approximately 5 minutes for the total operation. If this is done before the heat is started, there is an unusual length of electrode from the holder to the end. If the electrode tends to slide sideways on an angular piece of scrap, there is a great chance of this long electrode breaking, so that it is better to have the short 5-minute delay than a much longer one caused by breakage.

### *Electrode Breakage*

Electrode breakage is one of the worst conditions the melter has to meet in melting of a heat and although of rare occurrence, may often be of serious nature and cause considerable delay. If the stub breaks off for a few inches, it may be burned out safely with no difficulty. If a stub over 1-foot long breaks off, it should be removed if possible. However, this stub often is down in a hole surrounded by an impregnable wall of scrap, in which position it is impossible to remove it. The only recourse is to lower the electrodes and allow the arc to break to this stub. Soon a pool of metal will be formed and it will then be possible to hook out the stub.

The worst condition of breakage is where a full length of electrode is dropped in the furnace, due to the joint giving way. Often this electrode breaks off in such a position that its top is even with the top of the roof. The only way this can be removed is to loop a small chain around it and pull out with the crane. A small chain always should be kept among the furnace tools for just such an emergency. If a long length of electrode falls

crosswise in the furnace and cannot be pulled out, it must be broken up with heavy bars and sledges and removed in pieces.

Under any conditions of electrode breakage, the main trouble to guard against other than delays, is the serious pickup of carbon in the metal. When the electrode stub is removed, a quick calculation will show the approximate amount of carbon dissolved and sufficient ore may be added to counteract this enrichment.

It is always good practice to have an entire length of electrode, consisting of two full lengths, set up in the vicinity of the furnace. In cases where it would become necessary to add a new electrode, a great saving in time is made by placing this substitute electrode in commission. It must be remembered that a shutdown of any length during melting not only is harmful from time wasted, but allows a needless amount of oxide to contaminate the bath, cold air rapidly combining with the heated metal.

#### *Bridging of Scrap*

Without a doubt, scrap bridging is one of the most dangerous troubles encountered in electric furnace work, and it is one direct cause of a majority of hearth difficulties in electric steel-making. After the electrodes have formed a small pool in the bottom, the arc is thrown in all directions, but the greater portion of its force is downward to the point of best conductivity. During melting down, when the electrodes have been digging themselves a hole, the arc has flared and tended to partly melt the scrap in the vicinity of these paths. This tends to weld the upper layers of the charge together, especially if of such a character as will tend to bind naturally, such as long, mixed bar iron.

The rising temperature of the pool, naturally aids in fusing the surrounding metal, and soon a regular roof of tightly fused scrap is formed in the furnace, just high

enough from the arc so that the radiated heat is insufficient to melt it down. The result is that the metal in the bottom becomes greatly superheated, causing the hearth to fuse and holes to start. As this refractory digs out, the hot steel is lowered, and the greater volume of slag formed helps further in keeping the heat from melting out this steel bridge. Continuation of this will result either in losing a hearth completely or in such a bad hole that it may be necessary to stop and burn in a patch.

There is no reason for ever allowing this to happen, as the furnace will give adequate warning. During the general melting down, the flame issuing from around the electrodes will be strongly oxidizing, and will be sharp and pointed, often bluish in color. However, as soon as bridging starts to any dangerous degree, this flame will quickly change to a soft, luminous, yellow color, accompanied by heavy white or black smoke showing that reduction is starting. As there can be no reduction in the presence of the iron oxide on the scrap unless trouble is ensuing one may tell quickly what is wrong.

There is only one antidote for such an occurrence, that is to break down the bridge, and often this is much easier said than done. However, it must be done, so the only way to go about it is to get hooks and bars, and start breaking down a little at a time. Often it may be broken in a few minutes, but there are times when it will take 15 or 20 minutes of the hardest work to accomplish that end. After being broken down, it is generally best to add several shovels of ore, to thin the slag, and to create sufficient boil quickly to throw any still adhering scrap into the bath.

Current may be interrupted by a shut down of the main source of supply, or may be the result of trouble in the electrical end of the furnace. If the shut down is of any appreciable duration, all doors and cracks should be sealed with a heavy mud to assist in holding as much

heat as possible, and to keep out cold air with its attendant oxygen.

The free melting of the charge on a 3-phase, arc-type furnace presupposes perfect contact throughout all portions of the metallic charge, if it is to act as a satisfactory neutral connection. Often due to dirty or heavily rusted scrap, poor contact is made throughout a portion of the charge, causing one of the electrodes to become isolated and lose its current connection. If allowed to proceed, the regulator will force the electrode downward and break it, or the cable on the electrode motor will unwind and often cause a snarl. Poor contact is seen when one of the electrodes refuses to arc, and the ammeter drops to zero.

Bars should be inserted in the furnace and the scrap under this electrode disarranged so that fresh surfaces may be exposed and contact picked up. If this will not work, several large size pieces of coke thrown directly under the electrode generally will carry the current long enough for contact to form underneath, the heat, fusing the pieces together. However, at times, all such treatments will fail, and the only remedy then is to raise the electrode and throw several hundred pounds of some good, clean scrap underneath. Charges containing a large amount of dirty borings or turnings, and those with sand covered ladle skulls, spill, etc., are likely to give poor contact, and this metal should be so charged that this danger is minimized.

#### *Avoid Power Surges*

During melting down, power surges should be avoided as they tend greatly to disturb the electrical system, and place undue strain on the regulator units. Surging usually is caused by a bad boil, an exposed patch of clear metal, or by scrap falling against the electrodes.

A boil may be stopped quickly by tossing a few



chunks of cold metal in on the spot, the chilling effect quickly calming down the metal. A normal boil should approach more of a heavy bubbling aspect than a series of violent churnings. Clear metal easily is overcome by the addition of a small amount of lime to form a slag.

As the bath is approaching a well melted condition, the main body of the scrap is undermined by molten metal. Often this suddenly slips, and a dead short is made with all three electrodes. This sudden strain, unless relieved, is likely to cause serious trouble with the electrical equipment. Of course, limit switches are provided such that any overload throws off the current, but there are times when something goes wrong with this equipment, and the main brunt of the strain is thrown upon the transformer. Constant repetition of this gradually will wear down the electrical equipment until a failure occurs, with its long and costly delay.

The remedy for this is to raise the electrodes as soon as the scrap approaches the falling condition, and poke it into the bath with bars. The walls may be well cleaned of metal and the current again turned on. It is much better to waste several minutes poking in than to allow the scrap to fall with the chance of breaking an electrode or ruining a transformer.

### *Overload Heats*

Often heavy, overloaded heats are placed on the furnace such as requiring a 3-ton furnace to pour 6 tons of metal. In many such instances it is impossible fully to charge the heat on one operation, and further scrap must be added after melting down. In such an instance, this practice is all right because it is a necessity but under any other circumstances this addition of cold scrap to a melted bath should be avoided rigorously.

In the first place it constitutes a heavy chilling effect, often a heavy skull being formed on the bottom, and

around the walls, requiring an unusual amount of energy to melt it free. Again, the addition of oxide to a melted metal does not improve quality, the metal in this pasty state being in exactly the right condition to dissolve a part of this unwanted element. It has been found in most instances that the time lost, and added power necessary, over-balance any gain from the larger sized heat, although there are melters who strongly advocate such practice.

Another point of controversy is the proper voltage with which to melt the charge, and whether two or more voltages are superior to one. To show to what extent this difference of opinion goes an examination of a few of the different furnaces on the market denotes the wide difference. For example, the Heroult furnace is installed with two different alternative arrangements; one having a single voltage of from 100 to 110, the other having a melting down voltage of approximately 130, with the transformer so arranged that various selections may be made for the refining voltage. In one particular shop the transformer was so arranged that there were six possible combinations ranging from 60 to 130 volts

This is standard on the majority of present furnaces. A new innovation was brought forward by the Pittsburgh Electric Furnace Corp., Pittsburgh. Appreciating the value of speed in the steel-making activities of a foundry, this company gains a point by using relatively high voltages, differing greatly from the present standard practice. The transformer is connected so that a voltage of approximately 238 is used for melting down, with a voltage of about 138 for finishing and refining. The natural result of this long arc is a much faster melting operation with its attendant economy.

On basic operation there is ground against the long arc in the fact that it is conducive to the fixation of nitrogen, which dissolving in the steel is the cause of every trouble from a plain gas bubble to a faint *ghost line*.

The author in operating this furnace on both basic and acid hearths has followed carefully the quality of the steel, and has found it to be the equal of quality of that made in other types of furnace.

On basic operation there is ground for the argument against such a long arc, as it tends to perform its melting so quickly that the action of the slag has not sufficient time to function thoroughly. On basic operation a melting down voltage of from 120 to 150 volts is recommended, with a refining voltage of from 90 to 110. On acid operations a melting down voltage of from 180 to 230 is right, with a refining figure of from 110 to 130 volts.

#### *Melting Down the Heat*

Assuming that none of the above troubles are encountered, the heat is allowed to melt down to the point where the scrap is beginning to undermine, when the current is shut off, the electrodes raised, and as much of the scrap poked in as possible. Often this is unnecessary, the scrap gently sliding into the pool as the bottom portions gradually are melted away. From this point on, the heat will require certain working to bring the first slag into a satisfactory condition. This first or dephosphorizing slag is composed of lime alone and may be added to the furnace in several different ways.

The lime may be charged directly on the hearth before the furnace is charged with scrap. While this practice is widely followed, it is not to be recommended as its use in this manner tends to build up the hearth. As the bottom of a basic furnace always tends to rise with the best of practice, requiring constant attention to cut back to shape, this is only causing extra trouble for the furnace crew resulting in an increase in lost time and giving trouble with the slags during this period.

The lime may be mixed with the scrap during charging or placed about the center of the charge, between the

layers of metal. The objection to this arises from the fact that lime is a poor conductor of electricity when cold and when placed in this manner might be so arranged that different parts of the charge would become insulated from the remainder, causing difficulty in making contact.

### *Lime Under Electrodes*

A third method is to add the lime under the electrodes as soon as the first pool of metal forms. Often this is performed by raising the electrodes when they have dug a deep hole, adding the lime and filling up these cavities with fresh scrap.

Extensive experiments have been conducted on this point by the author and more uniform results were obtained by the latter practice than by any other. This is the hottest point in the furnace and it is easy to strike an arc in the presence of these hot gases regardless of whether lime is present or not. Furthermore, this is the point where the greatest amount of physical action is had, due to the churning of the metal by the force of the arc. Consequently, this lime is mixed rapidly to form a slag and always being exposed to any oxide as the scrap melts, tends to pick up the oxide before it has any tendency to dissolve in the metal.

How much lime is needed for this slag? Assuming that the amount of phosphorus to be eliminated is about 0.03 to 0.04 per cent, it will be necessary to add sufficient lime adequately to carry this amount. In addition to the amount of lime necessary to carry off the phosphorus, sufficient must be present to form a slag with the silicon, the manganese and any foreign matter in the charge, besides having enough to form a blanket for the metal. As much heat is necessary to melt and hold this slag liquid, this heat is wasted as far as its effect on the kilowatt hour per ton of metal value is concerned, the minimum amount

which will adequately satisfy all of the above points must be used.

Experience has taught that an amount of lime equal to from 2 to 4 per cent of the weight of charge is sufficient to satisfy all the foregoing points. This amount will vary, depending upon the phosphorus to be eliminated, the cleanliness of the scrap and other considerations. It does not have to be accurately weighed, but can be calculated by the scoopful and about half thrown in the holes under the electrodes as the heat melts, the remainder

Table XVII  
HOW SLAG ELIMINATES PHOSPHORUS

No additions of ore or scale, other than on the scrap in the form of rust; no boiling, and slagging off as soon as the heat was sufficiently melted.

Pounds Lime	Per cent Phos. in slag	Per cent removed from steel
540	1.03	0.032
530	1.30	0.050
570	1.31	0.064
540	0.95	0.081
550	0.85	0.089
420	0.59	0.065
560	0.72	0.050

being added as soon as a fair-sized pool is formed. The entire amount ordinarily will be in the furnace approximately 45 minutes after the current is on, in a furnace taking about 2 hours to melt the charge. As the metal melts, all impurities and the oxidized alloys contained rise to the top and slag with this lime. This forms an excellent blanket of rather thick slag which is a decided advantage. This thick body of slag does not radiate heat well, the main body of the heat being transmitted to the steel bath below, a minimum of the arc's radiation being thrown against the roof or side walls.

#### *Phosphorus Removed*

Tests made on a 6-ton Heroult furnace, melting approximately 8 to 9 tons in a charge largely made up of railroad wrought iron, show the effect on phosphorus

removal. The results of this test are shown in Table XVII.

The amount of phosphorus eliminated may be increased by the addition of sufficient amounts of ore to keep the bath in a steady boil or in special cases more than one dephosphorizing slag can be used.

As the heat melts and this slag becomes more contaminated with oxides, its viscosity is lowered. It often becomes thin and runs like water. When this occurs more lime must be added to keep this slag in a fairly thick condition. When the bath has melted completely and is hot enough to retain its molten condition for 10 or 15 minutes, the current is shut off and slagging off begins. Flat, hoe shaped, rabble bars are used to push the slag toward the tapping door, or in certain makes of furnace, toward the slagging door, where it is pulled out with bars or hooks. Often the rabbles are made with a wooden edge, as these are more suitable for raking the slag and the metal does not adhere to its surface. As soon as the greater part of the slag has been removed in this manner, a further addition of lime is thrown in the furnace and the metallic bath absolutely cleaned of any remaining slag. The furnace is tilted back into normal position and is ready for finishing the heat.

#### *Chemistry of the Melting Period*

The initial charge, from a chemical standpoint, consists of an iron base together with certain amounts of iron oxide, manganese, silicon, carbon, phosphorus and sulphur. Of these, the iron oxide is the most important as it furnishes the necessary oxygen for the action of the first slag or the oxidizing period. Iron combines readily with oxygen from the atmosphere to form iron oxide, or rust as it is commonly known. This is in the form of  $\text{Fe}_2\text{O}_3$  at normal temperatures. At temperatures of 800 to 900 degrees, the combination of iron with oxygen be-

comes rapid and scale is formed. This can be represented by  $\text{Fe}_3\text{O}_4$  or  $\text{FeO} \cdot \text{Fe}_2\text{O}_3$ . This always is formed when free iron is heated to this temperature in the presence of either air or steam, from the reaction



But at temperatures over 1000 degrees with iron in contact with carbon dioxide another form of iron oxide may be formed,  $\text{FeO}$ .

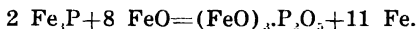


There are other possible ways for oxides of different kinds to be formed but from the standpoint of practical furnace operation, the above generalizations serve as excellent examples to show the reactions involved.

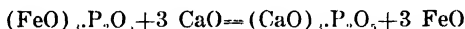
As all scrap metal contains an appreciable amount of rust, this is one large source of the oxygen needed. Then, in the melting down period, the furnace doors never are sealed completely, so air is drawn freely into the furnace from the outside atmosphere. This furnishes another source of oxygen. On the general run of low carbon steels, such as the present example, these amounts of oxygen are more than sufficient and may safely be considered as providing an excess of oxygen and requiring no ore to complete the reactions.

Phosphorus is oxidized easily when in the free state, by oxygen alone to form the pentoxide  $\text{P}_2\text{O}_5$ . In steel, phosphorus is combined as iron phosphide,  $\text{Fe}_3\text{P}$ , with up to about 1.7 per cent P, having a melting point of approximately 910 degrees Cent. As the metal becomes heated to this temperature, the iron phosphide melts and combines with oxygen to form the pentoxide. From this point all iron in the bath may be considered as  $\text{FeO}$  in making our calculations. This phosphorus pentoxide is an acid and must be neutralized as soon as formed, which under this process is naturally an automatic action in the presence of the heavy lime slag. The reaction by

which the phosphorus is removed from the metal may be represented by



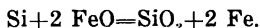
This reaction will be in process before and during oxidation of the silicon to silica, but the phosphorus will never be completely removed from the metal until all of the silicon has been eliminated. Silicon has the power of replacing the phosphorus pentoxide in the ferrous phosphate and exposing this oxide to further reactions. This power of silica accounts for the fact that phosphorus never is removed by any of the acid processes for making steel, because the formation of this compound is prevented by the high percentage of silica in the slags and the consequent retention of the silicon in the metal. In the basic process, the large excess of lime is sufficient to neutralize this silica so that not only is the ferrous phosphate allowed to form, but on reaching the slag is converted into a stable calcium phosphate:



However, this salt easily is reduced and the phosphorus only will be held by the slag as long as the temperature is highly oxidizing and in the presence of a heavy lime slag, which is distinctly basic.

Silicon, under the influence and conditions of the electric furnace, forms but one oxide, that of silica,  $\text{SiO}_2$ . The tendency of silicon to combine with oxygen is even stronger than that of iron, due to the greater heat of formation of the oxides. This makes it capable of reducing any of the iron oxides and upon this fact is based the elimination of this metal from the molten steel.

Since at this temperature the most plausible oxide to suffer by this reaction is  $\text{FeO}$ , this elimination may be represented by



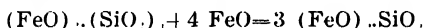


### Slag Formation

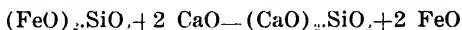
Immediately the reaction is completed, the silica combines with the iron oxide to form a bi-silicate, trisilicate or even some more complex salt of the two compounds, depending on the amount of the base present. This, from a practical standpoint will occur most probably as



This ferrous silicate is in the fusion state, due to a lower melting point than that of the metal and being of lower density than the steel, rises to the surface and combines with the lime to form a slag. Here further changes may ensue. This silicate when first formed, was in the presence of a limited amount of base. With the ever present excess of lime, this silicate may change to the monosilicate from its previous state of a trisilicate:



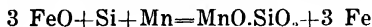
The ferrous oxide thus combined becomes inactive, but is released to go back into the bath by the combination of this compound and the lime of the slag:



This form of a calcium silicate is stable and safely holds all of the silica in combination under oxidizing, basic conditions. This calcium silicate forms the major part of the first slag in the electric process, but never is freed from the oxides of iron, due to its ability to hold them in solution.

Manganese with oxygen forms probably as large a number of oxides as any other metal, but under the conditions of the electric furnace only one exists, that of the true oxide  $\text{MnO}$ . Like silicon, the manganese alloyed in the metal as a carbide must be oxidized largely through the agency of iron oxide. However, as silicon is capable of reducing this oxide, it follows that manganese cannot

be eliminated until the bath has been cleared of all silicon. Manganese may be considered as being eliminated coincident with the silicon following the equation

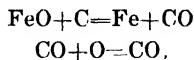


When this silicate of manganese reaches the heavy lime slag, it follows the condition of the previous ferrous silicate, under silicon. The manganese oxide combines with the lime and the silica is freed as has been shown, ultimately combining with the lime.

The manganese oxide will remain in the slag as a free oxide as long as the slag contains an abundance of iron oxides. If the supply of these were to become depleted, the manganese oxide becomes susceptible to reduction, the metallic manganese being reduced back into the steel. This will only happen under a reducing condition and will be further explained under the final slag period.

### *Carbon Reactions*

Carbon reacts differently from any of the elements previously explained. All of the combining reactions are exothermic and result in the formation of a solid compound combining with the lime to form a slag. The elimination of carbon causes an endothermic reaction, giving as a product the gas, carbon monoxide, CO. This rises up through the metal and into the slag where it is held in a loose or free condition. This gradually penetrates the slag blanket, causing a bubbling or what is known as the *boil*, which is often more or less violent. The gas issues from the furnace around the doors and electrode openings and burns with the oxygen from the air to form carbon dioxide.



The operation of slagging off signifies an elimination of the oxidizing period and a change over to the period

of reduction for the purpose of finishing the heat. Therefore, before the heat can be slagged there are certain conditions which must exist. They are:

The carbon content of the metal must be at the desired point.

Manganese, silicon and phosphorus must be as low as is desired.

The slag itself must be of the proper consistency and degree of oxidation.

At this point in operation, the charge is melted and the slag has formed, resting on the metal as a thick, viscous blanket. The metal still is cold and heavily impregnated with oxides, both in combination and held in solution. Due to this condition the slag is jet black in color. It is now good practice to put a bar in the furnace and clean the walls of any small pieces of adhering scrap. If there are any large bodies of scrap on the walls they are pried loose and shoved into the bath. The bar is now run over the bottom to make sure there are no *nigger heads* or bodies of unmelted metal resting there. If any, they must be pried loose, for if allowed to remain they will come up later when the temperature of the metal rises, projecting a large amount of oxides into the second slag and causing much difficulty in their reduction.

### *Preliminary Tests*

As soon as all loose pieces of metal are melted and the surface of the bath is free from floating steel, it is time to begin final operations. The first of these will cover the percentage of carbon remaining in the metal. A test spoon is inserted through the door and a metal test taken, the spoon being rotated in the slag until a good covering is assured, as a preventative to metal sticking to the spoon. This molten metal is poured into a chill mold, made of two cast iron blocks, to give a test piece approximately 1 inch square and 6 inches long. This metal will be wild, sparking heavily while being poured

and solidifying. There will usually be a heavy skull remaining in the spoon, signifying that the temperature of the metal is low. As soon as solid, this test piece is water quenched and broken.

There are many different ways of taking these test blocks and cooling them down preparatory to breaking. Some melters prefer to chill quickly in water, some allow to chill slowly in water by immersing and then withdrawing, while others allow the piece to cool in the air to a black. Any method gives the same results, but it must be remembered that all such tests must always be handled under exactly the same conditions.

This breaking is accomplished by placing the test bar on two rigid supports and striking with a heavy sledge hammer. Low carbon tests when so struck emit a dull thud and tend to bend before breaking. This is especially true for carbons under 0.15 per cent. Higher carbons will snap off easily on the first blow. From this degree of bend and from the appearance of the fracture, the amount of carbon present is determined. If desired, a sample can be sent to the chemist for a check analysis, but ordinarily on these first tests the melter can judge so accurately that such a step is unnecessary. Low carbon tests will show a blowy appearance and the crystalline structure will have the appearance of having rather been torn apart than broken. The grain size of the metal will be large and the fracture will show fiery.

#### *Lowering the Carbon*

On heats of low carbon steel, this present percentage should not be over 0.15 per cent. If under this figure the heat may proceed, if not, the carbon must be lowered. On all such heats, melting in the basic furnace when the initial charge contains approximately 0.20 to 0.30 per cent carbon with standard amounts of manganese and silicon, the rust in the scrap will be sufficient to cut the molten

metal down to such low figures as carbon, 0.05 to 0.15 per cent; manganese, 0.05 to 0.20 per cent and silicon, 0.02 to 0.06 per cent, in the great majority of cases. Under such conditions, the percentage of carbon is a good indication of the amount of the other alloys present. If the carbon is low, it is safe to assume that the other elements also are low, for the reason that they tend to oxidize out of the metal before the carbon begins to drop.

If a high carbon test is shown, the manganese and often the silicon will also be up and it will be necessary to add ore or some other form of oxide to boil out these elements. Ore should be added in amount of about 25 pounds at a time, each addition being allowed to work before a further amount is added. These small lots will soon cause an evolution of gases as the elements are oxidized which give rise to the familiar *boil*. This bubbling should be allowed to proceed slowly, but constantly until the carbon, on test, is low enough. On a 6-ton furnace, it will take approximately 15 minutes to lower the carbon 0.05 per cent, depending on the amount of manganese present, as this must be oxidized before the carbon will be attacked.

Many shops use other materials than ore such as mill scale, cinder, or crushed ore, for producing this oxidizing condition. The author prefers ore in lumps about 2 to 4 inches in diameter on account of its penetration of the slag immediately after being thrown into the bath. The other materials tend to float on the slag and work on the metal only in an indirect manner. However, this is merely a matter of opinion.

# VIII

## THE BASIC SLAG

THE chemical composition of the metal being correct, the slag is brought to its proper condition. This first slag should be dull black in color, and strongly basic. It should be rather tough on fracture, and should have the appearance of a piece of lava. If too thin, more lime should be added to thicken it; if too thick and lumpy it can be thinned by the judicious use of a small amount of crushed fluorspar. A thin, glassy slag shows the presence of too much silica and may be even tending toward an acid slag. Such a thin slag will have no effect on the phosphorus, allowing this element to pass back into the metal. Slags in the presence of a high percentage of carbon and manganese will show a dark brown color, this being an indication of reducing conditions. Such a slag must be converted into the black, lava like slag before it can act as a remover of phosphorus.

Satisfactory first slags usually will follow close to the following analysis: Silica, 10 to 15 per cent; manganese oxide, 7 to 10 per cent; iron oxide, 10 to 15 per cent; lime, 45 to 60 per cent; magnesia, 4 to 8 per cent. and phosphorus pentoxide, 2 to 4 per cent.

Both burned lime and limestone are finding wide use for building electric furnace slags, especially on the first slag. Burned lime has an advantage as less of this material is required per ton of steel, but this is obtainable at a slightly higher cost for the initial product. Limestone is much cheaper and while calcining tends to cause an auxiliary boil in the furnace. This tends slightly to counteract the power necessary for calcining. Either may be used during the oxidizing period with equal success, when working on the general classes of soft or medium steel castings. Limestone never should be

used in reducing slags or in high quality heats, due to the fact that one of the products of its calcination is the gas, carbon dioxide with one free atom of oxygen at high temperatures in the presence of carbon, this oxygen when freed requiring increased reduction to eliminate.

#### *Finishing the Heat*

The furnace having been cleared of the first slag, it is tipped back into normal operating position and ferromanganese added. The amount thus added is calculated either from results of previous heats of the same scrap character or from the result of the chemist's analysis of the preliminary test. Under general operating conditions, the residual manganese in heats of this kind may be closely estimated at from 0.05 to 0.10 per cent with a high degree of accuracy. The manganese may be added as calculated to the point desired, no loss being figured in this reducing operation. I have made thousands of heats of this soft carbon steel calling for manganese 0.30 to 0.40 per cent, the manganese addition being calculated at 0.30 per cent based on the weight of the charge, with few analyses, although no chemical analysis was made on the preliminary test. This alloy should be broken into pieces the size of one's fist and after being added, given a few minutes thoroughly to diffuse throughout the metal.

The second or deoxidizing slag may now be made and added to the furnace. This slag will consist of from 2 to 6 per cent of the charge's weight in lime; about 20 to 30 per cent of the lime, crushed fluorspar and 4 or 5 large scoops of finely ground coke. The exact composition of this slag will depend upon the amount of sulphur to be eliminated from the metal.

#### *Describes Finishing Slags*

The two classes of finishing slags are the ordinary white lime slag and the white carbide slag.

The white lime slag makes a compound pure white in color which on exposure to the air, disintegrates to a fine white powder. Generally, it is made of lime, coke and spar in the ratio of about 8 to 10 of lime, to 1 of coke and 1 of spar, making a slag with about 25 per cent acids to about 75 per cent bases. Such a slag is not strongly reducing, but tends to act more as a protective blanket for the metal than anything else. Lime is thrown upon the bath until there is a fair covering, when the slag is given a heavy dusting of coke and allowed to heat. If the slag appears heavy, additions of sand or spar may be made, spar being preferable, due to the fact that it furnishes a better thinning effect, together with its basic composition eliminating any tendency to dilute the basic effect of the lime slag.

Deoxidation with such a slag is not rapid and never can be accomplished finally without the use of ferrosilicon. The oxides in the bath, under such a slag, gradually will rise to the surface as the temperature of the metal increases. Here they will combine with the slag, the oxygen being eliminated by the crushed coke. Deoxidation by this method will proceed slowly and even after several hours under this slag, the metal will still show wild. The method of operation is to bring the slag into such a condition that it powders on exposure to the air, when small amounts of ferrosilicon are added until a solid test is obtained when the final additions can be made and the heat poured.

While the degasifying effect of such a slag is not of the highest quality, there is one great advantage. There is no appreciable carbon absorption from this slag into the metal. While this is important when working on heats of a low carbon content, it is not sufficient to overcome the many disadvantages, for deoxidation is too slow and is never certain. To really deoxidize the metal, it is necessary to make constant additions of ferrosilicon.



Such additions have as a product the non-metal silica which often may remain in the metal as inclusions. There is no certainty that oxides in solution or combination with the metal will be removed in such a manner.

Consequently, the use of such a slag is limited to the poorer grades of steel in which the carbon content must be kept low. In such a case, the amount of lime necessary only will have to be enough thoroughly to cover the bath, 2 per cent of the charge being plenty.

### *Carbide Slag*

Carbide slag is used in cases where absolute deoxidation is required, and where sulphur is to be eliminated. It consists of from 4 to 7 per cent of the charge as lime, depending upon the sulphur content desired in the finished metal; about 30 per cent of the lime as spar and about 50 pounds of coke dust.

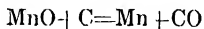
This slag upon exposure to the air disintegrates into a gray powder, giving off a strong odor of acetylene when coming in contact with water. Such a slag has strong powers in eliminating any gases present. A heat of steel made under this class of slag gradually will settle itself down, requiring a minimum of alloys to produce sound castings.

Whatever type of slag is to be used, it should be made up on the furnace platform and all lumps broken and thoroughly mixed before being added to the furnace. If the carbon content of the steel is extremely low and there is a considerable leeway between the present figure and that desired, it is excellent practice first to dust the entire surface of the steel with ground coke, and quickly add about half of this second slag. Another coke dusting then may be made on the surface of the slag and the doors tightly sealed.

During the period of slagging off, the bath has become covered with a scum of oxide, from the air. As soon

as this second slag is added to the furnace, it combines with this oxide and changes color from a pure white to a dead black. As the temperature rises and deoxidation proceeds, this oxide gradually is eliminated, the color turning to a dark brown, a light brown, a gray and finally to a steel gray, powdering in the air. This slag will tend to foam in the furnace, especially around the electrodes. The remainder of the slag mixture now is added and the furnace allowed to run until a slag of the proper consistency is obtained. This slag will transmit the greater part of the heat to the metal below, radiation to roof and walls being kept to a minimum. It will not attack the banks and will rapidly eliminate gases and sulphur.

At the start of reduction, immediately after slagging off, the metal is in a highly oxidized state, analyzing approximately 0.08 per cent carbon, 0.01 silicon and 0.08 manganese. The ferromanganese added raises this figure to about 0.35 or 0.49, the manganese immediately starting its deoxidation by combining with the iron oxide:  $\text{Mn} + \text{FeO} = \text{MnO} + \text{Fe}$ . This manganese oxide, being lighter than the metal, rises to the surface, combining with the slag. This slag, due to its heavy covering of coke, is highly reducing and the manganese oxide is immediately acted upon:



The carbon monoxide burns at the roof ports to the dioxide and the manganese goes back into the bath. This circle of reactions is kept up until the bath is thoroughly freed of all oxides, when the manganese remains in the steel as an alloy. This reaction to take place with favorable results requires a minimum of about 0.30 to 0.35 per cent manganese present in the metal.

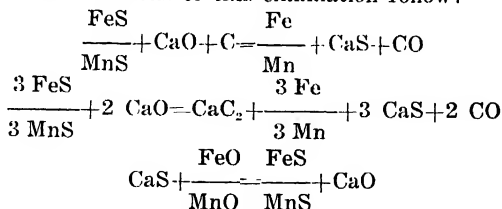
The slag, when first thrown into the furnace, picks up a heavy charge of iron oxide from the metal itself. This is acted upon by the coke, coincident with the pre-

ceding reaction and results in forcing iron back into the metal:



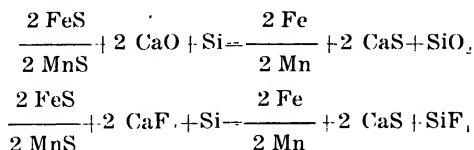
Therefore, the combined result of these two reactions is to free both the steel and the slag from their charge of oxides, resulting in sound metal and a powdering slag.

As soon as this condition is reached, the free lime in the slag begins to combine with the coke to form calcium carbide. This first occurs directly under the arc, but gradually proceeds over the entire slag, resulting in the familiar smell of acetylene when such a slag is quenched in water.  $\text{CaO} + 3\text{C} = \text{CaC}_2 + \text{CO}$ . It is at this point that absolute deoxidation and desulphurization begins. Whether manganese or iron sulphide plays the most important role in this, is difficult to decide, but that the gases and sulphur are removed cannot be doubted. The sulphur is removed by being changed into the insoluble calcium sulphide. The reactions of this elimination follow:



This presence of calcium carbide, with its attendant acetylene, thus is shown to be a sure indication that the bath is deoxidized, but under no condition should a heat be poured on this proof without taking a final metal test. On a low carbon steel, it often is impossible to keep a heavy covering of coke, due to the carbon being accessible to combination in the metal. In a case of this kind, when working under a rigid specification, sulphur may be removed by the use of silicon. This is another reason why

about 0.05 to 0.10 per cent silicon always is added in the working of low carbon steels before a solid test is obtained. The reactions follow:



This last reaction is made possible by the addition of fluorspar to the slag, the silicon fluoride being given off as volatile matter. The amount of silicon necessary for these reactions is close to the theoretical amount, but a slight excess always should be provided as these reactions will take place only after the deoxidation of the bath. Table XVIII shows analyses of finished basic slags.

Table XVIII

## ANALYSES OF FINISHED BASIC SLAGS

	1	2	3	4	5	6	7	8
Silica . . . . .	17.57	7.18	12.76	11.56	19.50	20.50	18.00	21.00
Iron oxide . . . .	1.33	0.35	0.16	0.31	1.00	0.71	0.40	0.52
Alumina . . . . .	3.12	2.17	.	.	.	.	.	.
Lime . . . . .	62.15	65.82	67.48	68.10	60.30	61.91	61.11	55.53
Manganese oxide .	0.36	0.05	0.25	0.29	0.60	0.61	0.32	0.40
Magnesia . . . . .	11.65	13.78	.	.	.	.	.	.
Calcium sulphide .	0.87	2.26	.	.	.	.	.	.
Calcium carbide .	None	1.54	2.26	3.10	1.30	1.48	5.60	5.31
Sulphur . . . . .	.	.	0.12	0.50	0.88	0.83	1.17	1.09

1 and 2. "Deoxidation and desulphurization in the Heroult furnace" F. T. Sisco "Chemical and Metallurgical Engineering" Jan. 1, 1922 No. 1 being for a white slag and No. 2 being for a white carbide slag.

Others from author's notes, the change in analysis depending upon the degree of desulphurization as evidenced by length of time the heats were held under this carbide slag. Nos. 3, 4, 5 and 6 were on steel casting heats, while 7 and 8 were taken from heats making forging steel for locomotive drive rods.

*Elimination of Sulphur*

Elimination of sulphur depends upon two variables; the amount of the carbide slag present and the time held under its influence. Therefore, to save time, it is possible to eliminate a stated amount of sulphur by adding larger volumes of slag. Such a procedure is naturally an economic feature, but there are certain limits above which the slag volume should not go. This figure may be set roughly as 7 per cent of the weight of the charge lime, amounting to a total slag equivalent to about 10 per cent of the charge in weight. Any amount above this point only results in delayed and costly operation.

In the elimination of sulphur certain points must be remembered and taken into consideration. To obtain a maximum of calcium carbide in the slag, the temperatures must be kept at a high figure, consequently the depletion of sulphur in the metal proceeds rapidly and care must be taken that the metal is not heated to such a figure as would cause trouble when poured. Of course, the antidote for this is to hold the metal in the ladle a certain time before pouring the molds, a point which constitutes good practice under any condition.

Then, too, this desulphurization will not commence until the heat has been thoroughly deoxidized and cannot be forced by doping the metal too heavily with silicon and aluminum. As this power depends upon the density of the lime slag, constant additions of lime and spar will be necessary as desulphurization proceeds, to keep the slag always in a rather thick, foaming condition. The efficiency of such a slag as a deoxidizer is lowered as the sulphur percentage rises, consequently it is mandatory that both a low sulphur lime and coke should be used for these operations. The maximum amount of sulphur capable of being eliminated in this manner is probably about 0.08 to 0.12 per cent from the steel, with a slag

volume not exceeding 10 per cent of the weight of metal. It is comparatively easy to reduce sulphur down to approximately 0.015 to 0.020 per cent, but to obtain lower percentages than these requires long tedious working, even though the initial sulphur was not over 0.050 per cent. However, there is no doubt but that for general purposes a steel with sulphur of not over 0.025 is as good as one with a sulphur of under 0.01 per cent so

Table XIX

## SULPHUR CONTENT WITHOUT FLUORSPAR

Carbon	Analysis of metal		Sulphur	Sulphur in slag	Distribution Coefficient
	Manganese	Phosphorus			
0.12	0.56	0.04	0.06	0.14	2.33
0.12	0.47	0.03	0.08	0.27	3.37
0.12	0.56	0.07	0.08	0.19	2.37
0.11	0.53	0.05	0.09	0.34	3.77
0.08	0.53	0.04	0.09	0.35	3.90
0.11	0.53	0.06	0.08	0.20	2.50
0.10	0.44	0.04	0.08	0.26	3.25
0.16	0.50	0.03	0.09	0.32	3.50
0.09	0.44	0.04	0.09	0.30	3.33

that this added desulphurization usually is not necessary nor required. In general the average amounts of sulphur eliminated by holding one hour under a perfect carbide slag will approximate from 0.020 to 0.050 per cent, depending upon the initial charge and miscellaneous conditions of refining.

*Using Fluorspar*

In the early days of electric furnace melting, sand was used exclusively to thin up the slag during the finishing, but of late years this practice has been superseded in the great majority of cases by the use of either crushed or gravel fluorspar. This is a natural mineral, usually containing over 80 or 85 per cent of calcium fluoride, the remainder being silica, iron oxide, calcium carbonate, etc.

It was noticed early in its use that excellent results were obtained, not only on thinning a slag, but from its ability to keep the slag strongly basic, even though thin enough to run like water. It also was noticed that when used, lower sulphurs were obtained than when it was not present, this being explained by the fact of its keeping the slag so basic.

Recently a paper on this subject appeared in *Stahl und Eisen* by S. Schleicher, which appeared in 1922. This is so important that it should be given adequate space

Table XX  
SULPHUR CONTENT WITH FLUORSPAR

Analysis of metal				Sulphur Distribution	
Carbon	Manganese	Phosphorus	Sulphur	in slag	Coefficient
0.10	0.38	0.02	0.05	0.32	6.40
0.13	0.47	0.03	0.05	0.32	6.40
0.08	0.32	0.02	0.04	0.30	7.50
0.17	0.50	0.05	0.06	0.38	6.30
0.15	0.47	0.02	0.01	0.26	6.50
0.13	0.44	0.06	0.05	0.30	6.00
0.12	0.53	0.01	0.03	0.20	6.60
0.12	0.41	0.02	0.05	0.33	6.60
0.12	0.47	0.03	0.06	0.36	6.00

and while the results were those obtained on open hearth work, the principles involved are directly applicable to the electric furnace and go a long way to explain certain well known phenomena. Mr. Schleicher says:

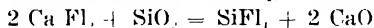
In Table XIX are shown the results with nine heats made from material extremely low in manganese and high in sulphur and in the working of which no fluorspar was used. The last column shows the sulphur distribution coefficient and is obtained by dividing the sulphur content of the slag by that in the steel. In other words, it shows the rate of the sulphur in the slag to that in the steel.

The distribution coefficient for these nine heats averaged 3.15. Table XX shows what a different result is produced when fluorspar is used and given the analyses

of nine, 30-ton heats, as before, using the same lime charge, but with the addition of 882 pounds of fluorspar.

The coefficient of these nine heats is considerably increased and averages 6.50. The steel of the first nine heats averages 0.08 per cent sulphur, which is above the allowable limit, while with the last nine heats it averages 0.05 per cent. The addition of fluorspar brings about a noticeable increase in the distribution coefficient and a decrease of the sulphur in the steel.

After the addition of fluorspar; the slag becomes very fluid. If the outgoing gases are conducted through water, the well known jelly-like precipitate of silica is formed which is always produced when silicon fluoride is passed through water. The spar has therefore reacted with the silica of the slag, silicon fluoride being given off as a fume, and lime formed according to the equation:



As silicon fluoride is formed, the calcium fluoride or fluorspar contents of the slag must decrease. This is shown by the following results, the first sample being taken immediately after solution of the fluorspar; that is, 10 minutes after addition, and the other samples at 10-minute intervals. The exact results of sulphur determinations in the steel and calcium fluoride in the slag were as follows:

Sulphur, per cent						
0.110	0.076	0.071	0.070	0.063	0.056	0.052
Calcium fluoride						
6.03	1.10	3.40	2.27	2.09	2.21	2.00

This shows that the decrease of the calcium fluoride only goes on to about 2.00 per cent, the samples taken during the last 30 minutes agreeing within allowable errors of analysis.

Seven finishing slags from seven heats in which fluorspar was used were then analyzed, as follows:

Calcium fluoride	Fluorine
Per cent	Per cent
2.58	1.26
2.40	1.17
2.44	1.19
2.30	1.12
2.16	1.05
2.48	1.20
2.06	1.00



Here also, with sufficiently long working, the calcium fluoride content of the slag is reduced to 2 to 2.25 per cent and then remains practically constant. Whether the fluoride was all present as calcium fluoride or in some other form, was not determined, but the assumption made was that it was as calcium fluoride.

Up to now it also has been assumed that desulphurization, when fluorspar is used, was brought about by the slag being made more basic and yet remaining fluid enough to permit a good reaction. The following results will show that desulphurization cannot be laid to this cause. The finishing slags of two similar heats, one made without fluorspar additions and the other with fluorspar are given in Table XXI.

Table XXI  
OPEN HEARTH SLAGS WITH AND WITHOUT FLUORSPAR

Without spar				With spar			
Slag		Steel		Slag		Steel	
per cent		per cent		per cent		per cent	
SiO <sub>2</sub>	15.20	C	0.16	SiO <sub>2</sub>	19.63	C	0.12
FeO	3.57	Mn	0.50	FeO	2.86	Mn	0.41
FeO	8.11	P	0.03	FeO	11.57	P	0.02
Al <sub>2</sub> O <sub>3</sub>	2.14	S	0.09	Al <sub>2</sub> O <sub>3</sub>	3.36	S	0.06
MnO	5.41			MnO	5.63		
P <sub>2</sub> O <sub>5</sub>	4.76			P <sub>2</sub> O <sub>5</sub>	2.62		
CaO	16.50			CaO	45.98		
MgO	12.97			MgO	1.55		
S	.32			S	.41		
CaF <sub>2</sub>	.			CaF <sub>2</sub>	2.26		
S Coeff	3.50			S Coeff	7.30		

Table XXII

Percentage Range of Elements with Fluorspar Additions

Time	C	Steel	P	S	SiO <sub>2</sub>	FeO	Fe <sub>2</sub> O <sub>3</sub>	MnO	Slag	Al <sub>2</sub> O <sub>3</sub>	MgO	S	P <sub>2</sub> O <sub>5</sub>	CaF <sub>2</sub>
2 15	0 165	0 15	0 026	0 081	19 40	10 80	2 14	17 07	16 80	2 08	1 16	0 11	2 68	
2 30	0 115	0 15	0 014	0 081	17 90	10 67	2 21	16 77	39 30	1 16	6 35	0 25	2 52	
2 32	440 lbs	spiegelogen	added											
3 00	0 175	0 44	0 016	0 081	17 85	10 67	1 57	17 28	31 90	2 57	6 85	0 16	1 50	
3 01	1984 lbs	fluorspar	added											
1 11	0 120	0 38	0 027	0 064	17 60	11 44	1 57	15 81	54 65	2 16	7 29	0 26	7 29	6 34
1 21	0 100	0 11	0 030	0 060	18 05	11 70	2 14	16 25	15 14	1 90	6 05	0 23	7 21	25
3 23	661 lbs	spiegelogen	added											
3 33	0 100	0 35	0 030	0 060	18 25	11 70	2 21	16 02	35 50	2 51	7 15	0 24	7 11	1 40
3 34	Heat tapped													

The basicity of the two slags expressed as the ratio of the oxygen of the bases to that of the acids is 1.67 in the first case, 1.30 in the second and yet the distribution coefficient in the first case is 3.50 and in the second 7.30.

To obtain conclusive information, the following

experiment was carried out: A 60-ton heat was taken and while working down, 4409 pounds of spiegeleisen was added. In half an hour the manganese was worked out and the bath was in such a condition that about half an hour's work with the finishing slag was required. An addition of 1984 pounds of fluorspar was made, the spar containing 95 per cent calcium fluoride. Samples of metal and slag were taken as shown in Table XXII. Especially striking is the fact that the silica does not decrease, but increases notwithstanding the fact that the calcium fluoride reacts with the silica as shown by the white smoke from the chimney after each addition.

To investigate the matter further, samples were taken from another heat giving results as follows:

Test	Time	Silica per cent
1	10:28	17.23
	10:30	1764 lb. spar added
2	10:33	17.05
3	10:37	16.18
4	10:43	17.08
5	11:13	17.70

This heat also shows the silica drops during the first seven minutes but then again increases. The slag takes up silica which must come from the furnace lining and it must be mentioned that there is a marked destruction of that part of the hearth and walls coming in contact with the slag. Through the fluorspar addition the slag has not become more basic. The sulphur in the bath, Table XXII, is lowered from 0.081 per cent to 0.064 per cent and then 0.060 per cent. However, the sulphur is not increased in the slag, but is decreased and to a greater extent than is accounted for by the dilution of the slag by the spar additions. The same results were shown by another heat as given as follows:

Time	Sulphur in steel per cent	Sulphur in slag per cent
10:55	0.081	0.233
11:00	1764 pounds of spar added	
11:20	0.060	0.165
11:40	...	0.182
12:12	0.042	0.220
12:13	Heat tapped	

A careful balance of the sulphur in the heat given in Table XXII shows that 40.54 pounds were volatilized. A test was carried out several times of taking outgoing

gas from the furnace between the port and the air regenerator, through a water cooled pipe and bubbling through potash solution. The average showed 0.22 grams sulphur per cubic meter and theoretically there should be 0.213 from the producer gas. Similar tests were made after the addition of fluorspar, but this method did not show an increase in the sulphur content of the gas. This shows that the sulphur is not in the form of the trioxide,  $\text{SO}_3$ , but there is the possibility of a fluoride being present, such as for example,  $\text{SF}_6$ . There is a possibility that such a compound would be precipitated by the low temperature of the water-cooled pipe so the gas was sucked hot through a porcelain tube and it was found that more sulphur was absorbed. The gas contained 1.966 grams per cubic meter and as 0.22 grams came from the producer gas, the remainder, or 1.766 grams, was volatilized from the slag. The amount taken for the test was 10 liters and the time was the seven minutes immediately following the fluorspar addition.

The conclusions drawn from the paper are:

If fluorspar is added to an open-hearth slag it is only decomposed and reduced to a certain limit, namely, from 2.0 to 2.5 per cent of calcium fluoride content. Silica is first removed from the slag as silicon fluoride, but immediately is replaced by silica from the furnace lining. Fluorspar is desulphurizing in its action in that sulphur is volatilized from the slag in some form, allowing the slag to absorb a further amount of sulphur from the steel.

### *Working the Heat*

When the final slag first is added to the furnace it tends to cake, due to its chilling effect upon the already rather cold metal. In about five minutes after adding the first portion, this slag should be well rabbled, and the remainder of the slag carefully dusted over the entire bath. In about 15 minutes it will have become molten, but on taking a test will show heavy and black. Further additions of coke dust can be made, and slag tests taken at short intervals. As soon as the metal begins to heat,

and deoxidation commences, this slag will turn to a brown color, and become rather porous in texture. Further reduction will change it to a light brown, then a dark gray, and finally into its proper powdering condition. During this period the slag should be rabbled occasionally to overcome any tendency to cake, and to assure of all the slag passing under the direct force of the arc. According to the consistency, additions of either lime, spar or sand may be required.

Slag too high in lime has a lumpy appearance in the furnace, the coke showing plainly on its surface. When poured and quenched in water, the test will show a light color, but will be thick and lumpy. Under these conditions it is hard for any entrapped gas to escape, and such slag will hold back the completion of the heat in a serious manner. A few small additions either of fluorspar or sand will rapidly thin such a slag and transform it into an excellent foaming slag, powdering on exposure to the air. Fluorspar is more beneficial than sand, due to its better power of desulphurization. A slag which comes up thick is beneficial from all points. It is a good carrier of heat and transmits most of the heat received from the arc into the metal with a minimum of radiation. It has poor powers of reflection, and is easy on the roof and walls. Such a slag will not corrode the banks, and is heavy enough to obviate any tendency of the coke entering the metal and raising the carbon.

#### *Slags Too Thin*

A thin, watery slag will reflect the heat badly to the roof and walls, resulting in a badly burned lining, will not heat the metal beneath, and will allow the carbon from the coke to contaminate the metal, resulting in a high analysis. Such a condition is caused by indiscriminate additions of sand, due to carelessness or a mistake in calculation, and immediately should be remedied by addi-

tions of lime. This quickly will thicken it, and bring it to its proper consistency. Such a slag has absolutely no powers either of deoxidizing or desulphurizing, and only results in delaying the heat, and cutting the banks. Such a slag may even pass over into one of acid composition, due to silica dropping from the roof and walls. A slag of this character will show either a whitish or a light blue, and will have a crystalline appearance when fractured, having something the appearance of glass.

Often, due to hearth troubles, the slag may become contaminated with magnesite either from the bottom or the side walls. This will result in a pasty heavy slag which it is impossible to clear. The only remedy for this is to make heavy additions of white sand and fluorspar until this heavy slag body is thin enough to pour. This slag should be drained from the furnace, and another one made. A sample of such a slag when water quenched and broken will have an appearance similar to porcelain, and will be strong and tough. Its color will run from a heavy black to a dirty, blue gray. It never can be converted into a finishing slag, and any metal poured under such conditions will never be of a suitable quality but will require heavy doping with aluminum to set quietly, and in the majority of cases will pour wild. Due to its dissolved oxide, such a steel will contain a large amount of cracks, tears, and inclusions all of which mitigate against its quality. If possible, the best thing to do with such a heat is to pour it into some cheap grade of bar stock, brakeshoes, sash weights, etc. However, in the ordinary shop such a recourse is seldom possible, and the heat must be finished under another slag.

Heavy additions of ground ferrosilicon sometimes will aid greatly in clearing such a slag, and at the same time assist in the elimination of gas.

In finishing a heat, a slag often will refuse to clear up, regardless of the amount of coke added. Such a

condition is frequently met, especially in making steels of low carbon and alloy content. In such a case, the melter must resort to the use of silicon to act as his deoxidizing agent. This is crushed fine and dusted over the slag, especially under each electrode. The immediate result will be a thinning of the slag, requiring more lime to keep in its proper condition. The slag will react quickly to such a treatment, turning a lighter color immediately. If the lime is added properly with sufficient spar to prevent caking, the slag will quickly turn into one of a proper carbide nature.

Working a slag properly is a subject which is hard to describe, for the reason that it is seldom that the same set of conditions are found. Each much have a special treatment to obtain the desired result in the minimum of time. Certain points may be mentioned. In the addition of either lime, spar, or sand, do not add a large quantity at a time, but distribute the addition over a period by adding small lots periodically. This will eliminate any over addition requiring a working back, with its lost motion. It also is good practice to rabble the heat well after each addition to mix thoroughly the ingredients with the slag. Tables 8, 9 and 10 in the Appendix give data on the manipulation of various types of slags. Take plenty of slag tests, and keep right after a heat with as little lost time for each operation as possible.

Assuming that the slag is in its proper carbide state, there is only the one remaining step of finishing the metal before pouring the heat. This consists of three main points: Solidity, proper composition, and right temperature.

#### *Deoxidizing the Metal*

The slag being perfect, foaming slightly, and powdering in the air with an evolution of acetylene on exposure to water, the heat is given another heavy dusting of coke. Coke does not have to be used in this con-

nection, anything furnishing a high enough carbon for perfect reduction such as coal, gas coke, or charcoal being eminently satisfactory. However, there is always a good supply of coke *finer* on the market, which may be obtained much cheaper than any of the other materials mentioned. The doors now are sealed tightly with a clay mud, or with fine lime if they are tight fitting. Heavy flames of a soft, luminous character, and of a similar character to those from burning oil, will now come from the furnace through the electrode openings. Soon the furnace will begin to snow, or give off a heavy soot, due to the intense reduction, which will tend to collect on the water cooled roof glands, gradually closing the opening. As soon as this occurs the furnace is under a perfect reducing atmosphere, and the metal rapidly will be freed of both gases and sulphur. If a certain amount of sulphur is to be eliminated, the metal will have to be held until this is accomplished. If not it is safe to proceed.

### *Keep the Doors Closed*

During this period it is well to caution against the constant opening of the doors of the furnace to take needless slag tests, allowing large amounts of oxygen containing air to enter the furnace. The author has seen perfect carbide slags thrown back to a dead black by such a careless procedure. It is always well to keep an excess of coke on the slag to prevent any turning back when it is necessary to take a test.

A metal test taken should now show solid or nearly so. If not, a small amount of ferrosilicon, figured to 0.05 per cent, should be added, and the doors again sealed. Another test taken in about 5 to 10 minutes in all probability will show sound metal. If still blowy, the same action should be repeated until an absolutely sound test is obtained. Care must be exercised to keep the slag in a rather thick condition during this period as the additions

of silicon have a tendency to thin the slag to a point where it loses the greater part of its reducing powers. Such a test at this point should have an analysis of approximately 0.15 to 0.18 per cent carbon; 0.35 to 0.40 per cent manganese; and 0.05 to 0.10 per cent silicon.

### *Determining the Pouring Temperature*

Proper pouring temperature for a heat of casting steel is one of the most important features in electric furnace operation. In the commercial shop, operating a 3-ton furnace, a wide variation will be noted during a week's run. On one heat, for instance, two or three castings will take the entire output, while on the following heat 3 tons of metal may pour 50 flasks. Consequently there are innumerable combinations, each requiring metal of a different temperature.

Naturally the metal must be sufficiently hot to enable it to run whatever class of casting is being made; it must be hot enough to pour the entire heat without skulling the ladle. Conversely, it must not be too hot as this implies a waste of power, and results in so scabbing and burning a casting that the time necessary for cleaning is unduly prolonged. While it is perfectly true that metal poured cold is of a better quality than that poured at higher temperatures, the point must be considered that in a foundry all operations must be carried on at the most economical basis, consistent with specified quality.

The proper temperature at which to pour a certain heat is a strict matter of experience, and due to the many variations, there can be no rule set for this operation. However, many different methods are in use at the present time for determining comparisons in temperature. Roughly speaking they may be classed under four main headings; The rod test, the skin test, the pour test, and the use of mechanical instruments or pyrometers



The skin test consists of withdrawing a spoon full of metal from the furnace, and noting the time, by watch, taken for the metal to skin over with the oxide scum, denoting the beginning of solidification. The test time for ordinary work, usually is 30 seconds, anything less denoting cold metal, while above this time is an indication of hot steel.

The rod test is made by inserting a rod into the steel for a specified time and withdrawing it quickly. The manner in which the point of the bar is burned denotes the temperature. If the rod is cut off short, the metal is hot; if cut off tapering the metal is medium, while if the rod is uncut or skulled the metal is cold. The rod must be left in the metal the same number of seconds for each test, and must be of the same size, or results will not show a true comparison.

The pour test is made by taking a spoon of metal, skimming off the slag, and noting with the eye the manner in which the steel pours over the lip of the spoon, and the time necessary for this metal to solidify in a chill mold. The degree of coldness can be judged by the skull left in the spoon, metal which is fairly hot pouring clean. Experience will show how much superheating is necessary above the point of a clean pour. This test gives as good, if not better results than the others. A few trials soon will show the melter how his metal is running, and he can assume safely that the metal will pour from the ladle in the same manner it poured from the spoon.

All of these tests are at the most only poor measurements of the actual temperature of the steel, as so many different points may change the result. The condition of the slag, the initial heat of the spoon before the metal is dipped, the amount of slag covering on the spoon, and the surface of the spoon's contents, the position from which the test is taken, etc., all are changing

conditions which interfere with the accuracy of the tests. It may be said that the tests always should be taken in exactly the same manner to be in any degree reliable. Certain conditions such as the following should be followed closely to observe standard results:

A cold, or nearly so, spoon, should always be used. It should be well rotated in the slag before dipping.

The test always should be taken from as close to the exact center of the furnace between the three electrodes, as it is possible.

The slag should be skimmed off as soon as the spoon is withdrawn from the furnace.

More accurate tests such as those made with pyrometers have not been accepted by the entire electric furnace fraternity for several reasons. Couple pyrometers require constant checking, and adjustment and may be off when needed. Further it is difficult to obtain any kind of a couple to stand the high heats of the furnace. Optical pyrometers are difficult to use, due to the inability to obtain proper *black body* conditions, but have been used for experiments directed upon the stream as poured from the furnace and ladles. However, as this is too late, if the temperature is wrong, it is generally of little use. All this extra equipment, and the proper care of same over a period of time, costs money.

Checking temperatures in steel making rapidly is beginning to assume importance, as it is recognized that the heat of the metal is a point of the greatest consideration if the highest results are to be obtained regularly. Experiments are being carried on daily with this idea in mind, and it is reasonable to assume that someone shortly will bring forth some simple instrument which actually will work under the changing conditions of the electric furnace.

### *Completing the Heat*

The metal being solid, and hot enough to fill the necessary requirements, it is now the proper time to begin

to adjust the metal to fill its specifications. If any more manganese is required it is added, as is the remainder of the silicon, and after about five minutes the heat may be tapped. This is the most simple case, but is one which is seldom found in regular operations, the carbon usually requiring some slight adjustment before the pour.

If the shop has a chemist, a sample should be sent to him as soon as the first solid test is made. It will take approximately 15 minutes to run a carbon and a manganese, and during this time the metal is being brought to the finishing temperature. From his analysis the required amounts of any further additions may be calculated, and the materials laid out. It can be assumed safely that the silicon content will be about 0.15 per cent on the first solid test, and any further additions of this alloy can be made on this basis, allowing about 10 per cent for loss. Manganese may be figured straight, the loss of this element being negligible. In bringing the carbon up many methods are in vogue. Pig iron may be used; coke, coal, or other carbonaceous material can be added and well rabbled through the slag; the electrodes can be dipped into the metal and carbon taken from them.

For heats where close analysis is required, pig iron will give by far the best results, a low phosphorus, low sulphur iron being used, and given time thoroughly to assimilate in the steel bath. Coke or coal, if thrown directly under the electrodes will generally enter the bath, figuring about 50 per cent effective. The use of electrodes is not favored due to the cost, and to the many variables changing the amount dissolved. Regardless of the method used, a final test always should be taken, and the carbon judged either by fracture or analysis. As soon as the metal is ready the ladle is called, and the heat poured.

If a heat of steel is poured without some device being

used to hold the slag back, the metal and slag when entering the ladle will be churned together, and the usual result will be that particles of slag will become trapped in the steel, later coming to light as inclusions in a finished casting, often resulting in its loss. These inclusions are not always visible. Steel may contain non-metallic inclusions even though they be too small to notice with the eye. These often cause castings to crack. They are a great aid to forming centers of segregation; and seriously interfere if the castings are to be heat treated.

Naturally, some method must be used to hold back the slag until the metal is in the ladle. The best of these is the skim gate, which is made by building a box like affair on the spout, with a small opening near the bottom of the front side. The furnace is quickly tilted, the slag pours up over this opening, and the steel underneath runs into the ladle from this aperture. As soon as the steel is out, the slag will then run forth to form its covering for the ladle. Another method often used is to throw enough lime into the furnace in front of the spout to thicken the slag at this point. This holds back the body of the slag until the furnace is nearly free of steel, when this thick barrier can be pulled loose with a hook allowing the slag to pour forth.

The author has found in pouring basic steel that if about 1 pound of finely crushed fluorspar per ton of metal is thrown into the stream of steel, during pouring, it greatly aids in bringing up any entrapped slag, by combining with it and so lowering its melting point, and viscosity, that it quickly rises to the surface.

#### *Adding Alloys to the Ladle*

Many shops, operating the basic furnace, make a practice of adding their final silicon as well as their final carbon in the ladle. Often a small amount of manganese also is added. The author is a firm believer in making

steel in the furnace especially on basic operation where all points favor such a practice. Coke added to the ladle never is effective, and its degree of absorption only can be guessed by the roughest of estimates. Other means of raising the carbon such as graphite flakes on the ladle bottom, carburite, anthracite coal, etc., similarly are to be avoided as results under such circumstances will be irregular at the best.

Manganese added in the ladle cannot have the necessary time thoroughly to mix with the metal before being poured. This results in hard spots in the castings, and

Table XXIII

## CHANGES MADE BY LADLE ADDITIONS

Heat No.	Test	Carbon	Silicon	Phosphorus	Sulphur	Manganese
A	Ladle test	0.13	0.16	0.030	0.035	0.60
A	Bot. ladle	0.51	0.12	0.045	0.039	0.60
B	Ladle test	0.12	0.12	0.039	0.037	0.60
B	Bot. ladle	0.48	0.11	0.056	0.042	0.58
C	Ladle test	0.15	0.13	0.022	0.031	0.73
C	Bot. ladle	0.59	0.13	0.047	0.042	0.76
D	Ladle test	0.41	0.14	0.020	0.029	0.72
D	Bot. ladle	0.53	0.12	0.042	0.035	0.72

heavy segregation. This is especially true of heats poured at a low, or medium temperature, and has been proved many times by closely checked experiments. In one particular instance, a heat of steel was poured into several nests of ingots for rolling purposes. Practically all rolled fine with the exception of three or four which were so brittle that they broke when dropped on the mill floor. Analysis showed slightly over 4 per cent manganese in these faulty bars. While this is an extreme case it only goes to drive home the lengths to which such segregations may go.

The addition of ferrosilicon to the ladle is widely practiced, but has no points which would recommend it.

In the first place, its addition will only dope up the heat. There is the same chance of improper mixing, and the greatest disadvantage is in its tendency to go into the slag to form an acid condition. The effect of such an acid slag condition will be to cause a heavy sulphur increase as the pouring progresses, due to the inability of the slag to hold its sulphur content. As all basic slags tend to go acid as the pouring progresses, due to the severe slagging action of this heavy lime slag on the acid ladle brick, this



Fig. 24—Typical Fractures of Cast Steel Base Plate With Carbon 0.30, Manganese 0.05, Silicon, 0.31, Sulphur, 0.031, Phosphorus, 0.038 Per Cent. the Lower Plate Has Been Water Quenched, While the Top Plate Is Annealed

further acidity caused by silicon only enhances such action.

### *Discourages Ladle Additions*

Some analyses illustrative of this point are given by Henry William Seldom in the *Blast Furnace and Steel Plant* of September, 1921. These are shown in Table XXIII.

These tests, while made on the open hearth furnace, are extremely good illustrations of the course of different heats when ladle additions are made. In electric furnace work the change in the phosphorus content would not be so noticeable, but it is probable that there would be a much greater change in the sulphurs, due to the greater amount carried under the electric furnace slag conditions.

*Final Deoxidizers*

During the past ten years there have been a large number of patented final deoxidizing compounds placed on the market, their avowed purpose being to eliminate the last trace of gas from the metal. They have been composed of every conceivable metal, but in the main have been metals with a high affinity for oxygen, such as manganese, silicon, calcium, magnesium, and aluminum. The latter has been in use for many years, and still is used



Fig. 25 The Upper Plate Is Annealed and the Lower Water Quenched, While the Analysis Is Carbon, 0.26, Manganese, 0.59, Silicon, 0.29, Sulphur, 0.027 and Phosphorus, 0.033 Per Cent

widely. Most of the patent alloys have been discarded, leaving the field to two main metals, aluminum and ferro-titanium, or as it is called ferrocabor-titanium. While aluminum has an intense action in eliminating gases from steel, and promoting solidity, it has several great disadvantages. Properly made electric furnace steel does not require the use of any such expedient to make it sound. The use of aluminum greatly increases the shrinkage and is likely to cause trouble in the casting from this reason. Further the product of the combination of aluminum with oxygen is the solid alumina, which may remain in the steel as non-metallic inclusion, and later may prove to be the starting point for a defective casting. Therefore its use is adding an undue cost to the foundry, and is tending to lower the quality of the metal produced. In extreme

cases, its use is mandatory, such as where a heat starts to go wild in the ladle, or when furnace trouble causes a heat to be tapped to save the furnace bottom.

However, titanium is a different proposition and its use is to be recommended. There are countless shops over the country who are making wonderful steel without the use of titanium, and there are others who make regular use of this alloy. Its use however and whenever used will always increase the quality of the steel, and it can be considered as a help with no disadvantages outside of its increased cost. This metal, titanium, in addition to its affinity for oxygen, has a strong affinity for nitrogen, and it is probable that a great deal of its value lies in the elimination of this gas from the metal. In combination it tends to form the nitride, or the oxide, both of which have low melting points and rapidly clear themselves from the steel by rising and entering the slag.

Both of the above should be added to the ladle after all the other alloys have been allowed to expend their deoxidizing power. The best manner to add these final alloys is in small sized pieces thrown in the furnace spout as the metal is running out. The metal carries them with it and as they melt they are thoroughly mixed by the churning of the steel.

As soon as the steel is in the ladle, and the slag begins to flow, several large scoops of lime are thrown in and mixed with this slag. This tends to thicken the slag and so lower its viscosity that it will, only with difficulty, combine with the brick lining. In addition, it furnishes an extra amount of a strongly basic material sufficient to overcome any slight tendency of the slag going acid through any such slagging action. This lime causing the slag to harden and thicken, has another advantage in that it tends to form a heated roof to the ladle, and saves a large amount of heat in this manner.

When all of the slag has entered the ladle a heavy cov-



ering of ground coke is added to prevent any oxygen from the air combining with the slag and tending to turn it back into an oxidizing condition, and causing the heat to go wild as pouring proceeds.

### *The One Slag Basic Process*

Previous portions of this chapter have covered basic practice in detail where it is intended to remove both phosphorus and sulphur. A modification of this process finds wide use. A great part of the present day scrap metal is that which has come from the basic, open-hearth furnace and naturally is low in phosphorus. Using such a mixture there is no necessity for the added cost caused by removing any phosphorus, as such metal usually will contain this element in amounts of under 0.04 per cent, and the standard steel castings allow at least 0.05 per cent, giving a sufficient leeway to allow for any pickup due to shrinkage of the charge. Naturally this has resulted in shortening the basic process, known as the one slag process for making steel.

In making metal under the one slag process for basic steel, the scrap is charged in exactly the same manner, but no lime is added with the charge. As soon as the metal begins to melt sufficient lime is added to enable the arc to pull a steady load, and to allow enough of a blanket on the metal to overcome any excessive loss of heat due to radiation. As soon as the heat is almost melted, the steel is given a heavy dusting of coke, and the second slag added exactly as before described, small portions being added consecutively. Coke is added, depending upon the allowable limits for the carbon in the metal. Soon the slag begins to turn from the black to the brown, and all further handling is done as has been described under finishing slags.

There are times, due to a rusty charge, when this small first slag becomes so contaminated with oxides that

any attempt to clear it will result only in a long and tedious operation. The best process to follow here is to pour off this slag as soon as possible, and then add the final mixture. This is a good practice to follow under nearly all circumstances, as pouring off this heavily oxidized slag means that there is less oxide to clear in the end, the result being a more rapid running of the heats. As soon as the metal is melted and sufficiently hot to hold its heat for a few minutes, the furnace is tilted and this first, heavily oxidized slag is run off. Such a slag will be thin, and dead black in color and readily will run from the furnace. To obviate unnecessary handling, this slag may be run into a bucket, allowed to cool, and the lump disposed of in one piece. As soon as the greater part of the slag has been removed, the metal will start to run. The furnace is tilted back, the manganese added, and the heat finished in a manner similar to the two slag process where phosphorus is removed.

While such a slag is intended to remove only the oxides and miscellaneous impurities, it also will remove a reasonable amount of phosphorus if handled correctly. For this purpose, the first slag is made of about 2 per cent of the charge, lime, added to the furnace during the melting down period. Under such conditions the first slag will be basic enough to hold a certain amount of phosphorus in combination. It is safe to figure that such a slag will remove from 0.015 to 0.025 per cent phosphorus from a heat containing an average amount of rust, without the necessity of additional boiling.

In operating under the one slag process, the only great difference will be in the manganese content, the steel for a required analysis taking considerably less of the alloy. In a charge averaging about 0.50 per cent manganese only about 0.10 per cent addition will be required to overcome the loss. While the first metal test will show similar to the two slag process in manganese

content the slag will contain most of the manganese, which will be reduced back into the metal during the finishing period. Under such circumstances it is preferable to have a chemist make an analysis of the metal if regular analyses are to be had.

### Carbon Picked Up

The melter always must bear in mind that his steel when up to a fair temperature, and under a strong carbide slag, always will pick up carbon. The amount so

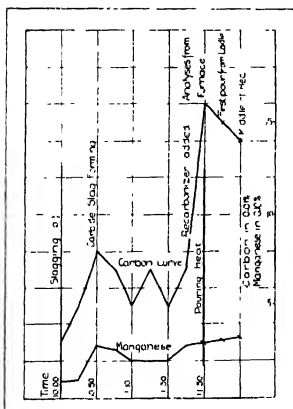


Fig. 26

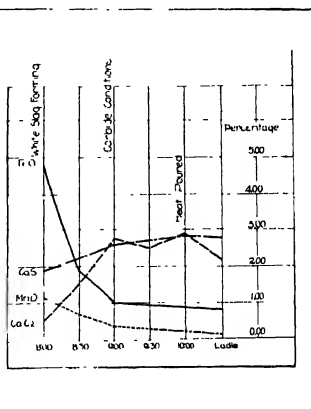


Fig. 27

Fig. 26-27—Variations in Carbon and Manganese During Progress of Heat

Fig. 26—The Charge Analyzed Carbon, 0.20 to 0.25 and Manganese 0.40 to 0.50 Per Cent, the Scrap Was Rusty and the Heat Was Run Under Dephosphorizing Conditions Without the Addition of Ore or Scale—Ferromanganese Was Added After Slagging Off

Fig. 27—Similar Curve Showing the Drop of Oxide Constituents and the Rise of Those Denoting Deoxidation

absorbed will depend greatly upon the volume and condition of the slag, the temperature of the slag and metal and the length of time so held. Every shop should deter-

mine their average gain in carbon, by making experiments, and then should allow for this when making additions. The general average will be from 0.030 to 0.060 per cent, assuming a slag of from 4 to 5 per cent of the charge by weight, and holding under a carbide atmosphere from 45 minutes to one hour. Experiments made on a 6-ton furnace making steel castings, and holding the metal under the white slag for 45 minutes, showed an average pickup of 0.060 per cent. However, in this case the metal was made rather hot which increased the rate of absorption. Other metallurgists have reported a pickup as high as 0.130 per cent in 45 minutes.

Melting with partial oxidation seldom is used when making low carbon steels, especially those under 0.40 per cent carbon, but is widely applied for the hard or medium hard grades. The charges here are made in a different manner, being so proportioned that the heat will melt down within a few points either way of a predetermined analysis. For example, assume a heat requiring a finished analysis of from 0.45 to 0.50 per cent carbon, with a manganese of 0.60 per cent. The steel will pick up approximately 0.06 per cent carbon from the slag, 0.050 per cent from the ferromanganese, making a total of about 0.10 per cent carbon before slagging off. If the rate of oxidation for the particular class of scrap to be used is 10 points on the melt down, without a boil, the charge of scrap can be made of metal analyzing 0.45 to 0.55 per cent carbon. Therefore this metal when melted will contain approximately 0.35 to 0.45 per cent carbon.

If the metal is allowed to remain under its oxidizing slag the result will be that the remainder of the carbon will be eliminated, requiring a considerable amount of work and recarbonizing material to bring it back to specification. It is advisable to stop this oxidation, and immediately start upon the finishing period.

If desired, this first slag can be run off and a new

one added. If this is practiced it will be necessary further to heat the metal to give the necessary temperature to the slag, to enable it to run from the furnace. During this heating the carbon will drop lower unless steps are taken to prevent such an occurrence. The best method of doing this is to add a small amount of either ferromanganese or ferrosilicon, and then dust the slag lightly with powdered coke. The force of the oxides are transferred from the carbon in the metal to these additions with the result that the steel analysis will remain constant which is an essential point.

If only one slag is used the carbon should be allowed to drop at least five points lower, and the metal heated. As soon as this point is reached add the ferro-alloy, and give a fair dusting of coke, immediately followed by the final slag materials. The amount of first slag to use will depend upon what disposal is to be made of it. If to be slagged, the first slag may contain at least 2 per cent of lime. If only one slag is to be used, the first slag should contain only enough lime to combine with any dirt or impurities in the scrap, and still remain basic.

#### *Using a White Slag*

Melting under a white slag rarely is practiced in the foundry, although widely practiced making high-carbon tool steels. The only time such a process is used in making castings is in certain cases where high carbons such as 0.70 to 0.80 per cent are required for use in crushing machinery where an unusually hard steel is necessary. In charging the furnace for such a heat, a certain amount of coke is charged with the scrap. During the melt down, the slag is added, and a small amount of coke added from time to time to furnish the proper reducing atmosphere. The furnace must be sealed tightly at all times, as an influx of air will destroy the desired conditions. The coke added must be carefully checked as an excess will make

the carbon too high. Under such an operation a carbide slag will be found on the metal, and if adjusted properly the steel will melt down to an analysis such that only slight additions will be necessary before pouring. Such practice requires a chemist on hand for the entire course of the heat, and for ordinary casting work does not give results commensurate with the increased care and cost.

## IX

### MAKING ACID STEEL

THE acid process of manufacture has become so important from a commercial viewpoint over the past five years that its procedure deserves the closest consideration. The common idea regarding the acid process is that its operations are so simple that a green man safely may operate a newly installed furnace. This naturally has resulted in many varying methods of operating an acid furnace, some good, others bad. It is the author's opinion that as much experience is required to make first class acid steel as the basic metal. Whoever has been held to rigid specifications on this process will agree on this point.

At first glance, the acid process offers merely a means of melting, and superheating a mass of steel to the pouring point, and teeming into molds. The final steel in such a case is no better than its preliminary charge of scrap, and often, due to poor operating practices, it is far worse. That this is the purpose of the acid electric furnace is a fallacy. While it is perfectly true that there can be no phosphorus elimination under the conditions of an acid slag, it also is true that there can be slight decrease in the sulphur content, due to its burning away under melting. The other components of the steel can be controlled closely, and by proper slag manipulation, the bath of metal can be deoxidized as well as under the basic carbide slag.

The rapid increase of acid lined electric furnaces is the best argument as to their ability to make a satisfactory grade of metal. Acid practice is rapid and economical. The product is high enough in quality to satisfy the most discriminating. The percentage of lost castings is low. The process offers exceptional opportunities for

making small, green-sand work, due to the high temperatures to which the metal may be heated. In short, for general steel casting work, the acid furnace offers as near perfect conditions as it is possible to attain. The personal element entering into its operation is the controlling factor.

Due to the insignificant reduction of any derogatory elements, the scrap used must be sufficiently low in phosphorus and sulphur to allow the finished metal to fall within allowable limits. As the present maximum limit of both sulphur and phosphorus in acid steel castings is 0.060 per cent this is a point which is rather easily met, almost any grade of open hearth melting scrap being suitable. This scrap should be segregated exactly the same as that for the basic furnace. However, greater care should be used to avoid large amounts of rust on the metal. Iron oxide offers a much different action on the acid hearth than on the basic. Under the conditions of the basic magnesite hearth, which is not attacked by oxide, this rust throws its entire strength to oxidizing the carbon, manganese, silicon, and phosphorus. The acid furnace bottom will be corroded rapidly by this oxide which may cause serious trouble in several ways, either by hearth cutting, or by bringing down the metal in an over-oxidized condition.

The acid furnace is rapid and there should be no lost time, if steady production is sought. Therefore, it is bad practice to boil the metal, or to have to recarbonize. Consequently, the balancing of a scrap charge becomes important. A charge consisting largely of shop scrap or other large chunks always will melt down high, requiring much manipulation to prevent excessively high percentages of the elements, particularly silicon. The opposite charge, one of all light scrap, will result in an over oxidized condition, requiring constant work to bring back to a solid state. Naturally a charge of clean metal will



come down higher than a furnace load of heavily rusted steel.

After running two or three heats on a new furnace it becomes easy to proportion the different classes of scrap so that the steel on the melt down always is approximately the same composition. In making up a charge several main points should be followed. These are:

Phosphorus and sulphur should be within limits.

The proportion of light to heavy metal should be about the same for each heat.

The physical condition of each charge should be the same as regards the amount of clean, medium and dirty scrap.

The chemical composition of each charge in carbon, manganese, and silicon should be kept as closely the same as possible.

If these points could be observed in a mathematical manner, the acid furnace would turn out the same grade of steel heat after heat without any supervision. However, this is impossible and it is these minor changes in the scrap which necessitate expert supervision, if steel of a constant and regular composition is to be made with a minimum of expense, and loss from unnecessary operations.

In charging the furnace for making the ordinary grades of soft steel castings the author has found that a charge consisting of about 25 to 30 per cent, heavy scrap, the remainder light shoveling steel, will give satisfactory melting conditions. This charge should analyze as close to 0.30 per cent carbon, and 0.50 per cent manganese as is possible with the scrap supply. If a large proportion of shop scrap is used, ore must be added to neutralize the added silicon, 25 pounds being about the correct amount to use in a 4 ton charge where not over 40 per cent is shop scrap, and where a final metal of under 0.26 per cent silicon is desired. If the scrap charge is rusty about 3 large scoops of old floor sand will give the necessary silica

to satisfy this oxide without its attacking the hearth. This also will give the necessary slag body to prevent *watery* conditions, with attendant oxidizing and radiating conditions.

If a slightly higher carbon is desired it is permissible to charge either a small amount of pig iron, or some carbonaceous material such as coke, graphite or coal, so that the charge will be stopped on the melt down, and give a higher carbon when melted.

### *Melting Down the Charge*

The charge being in, the current is turned on and the melting commences. The doors should be kept closed as much as possible during this period to conserve heat, and to keep air from the bath. The author does not favor sealing the doors and making the furnace absolutely air tight as this will cause reducing conditions when they are not desired, with the result that the bath comes down too high, especially in silicon.

During the melt down period, the furnace will be subject to the same delays as on basic operation which will be handled in a similar manner. However, there is one condition, which should be watched, more carefully, that of *bridging* of the scrap. If this is bad on the basic hearth, it is fourfold worse in the acid furnace, due to the fact that a basic slag will conduct the current easily, while the acid slag is a poor carrier of electricity. Consequently if the hearth begins to dig, the arc instead of flaming to the slag, will be forced to dig under to reach the metal. Naturally, the result will be that as the small body of metal digs, the depth of the slag increases, becoming much worse each moment, until the arc will dig completely through the hearth. The best indication of proper melting conditions is the color and character of the flame arising around the electrode ports.

At the start of the heat, and for probably the first

half hour this will manifest itself by a heavy reddish, brown smoke with little flame. As a pool forms, this brown smoke will change to a light yellow, accompanied by a reddish flame, which is rather sharp and irregular. As soon as the scrap begins to fall in from the walls, the red smoke recurs, but is not accompanied by heavy gusts of reddish flame, and often by dense puffs of heavy black smoke. As soon as the metal is all in, the color again changes to that of the yellow fume, until reduction begins.

This is the appearance of a furnace melting down under satisfactory conditions. If *bridging* begins an entirely different appearance will be noted. About 30 minutes after the power is on, and when the electrodes are down rather deeply in the charge, the smoke will change to a dense white. This is the first sign of danger, but does not necessarily mean bridging. If this is soon accompanied by a soft, luminous flame, of a deep yellow color, it is an absolute indication of hearth cutting. Unless immediately overcome, this flame will continue accompanied by ever increasing amounts of white smoke, until soon *snowing* begins. This is caused by the carbon of the electrode reducing the silica of the slag in the presence of the arc. The free silicon, in the form of a vapor rises, and as it leaves the furnace is precipitated by the cold air in the form of a heavy grayish powder resembling snow in texture. The author has seen this come from a furnace in lumps as large as the fist, it having a soft, open feel to the hand, crushing to a fine grained powder when squeezed.

If *snowing* occurs, it is a sign of absolute danger, and if the bridging cannot be broken, the electrodes must be raised and as much molten slag pulled from the furnace as is possible, when fresh scrap can be added to the holes and the arc started on this higher metal. Often the charge is so badly bridged that it is impossible to reach the holes from the doors. In such a case, the electrodes

must be raised and fresh scrap added through the ports in the roof, the scrap being added high enough so that contact will be made with the bridge portion. It is here allowable to add a small amount of ore, about 25 pounds being ample, to take care of thinning this heavy slag, and to start sufficient of a boil to tend to undermine the fused scrap and allow it to fall into the pool.

Under any condition as soon as a fair sized pool has

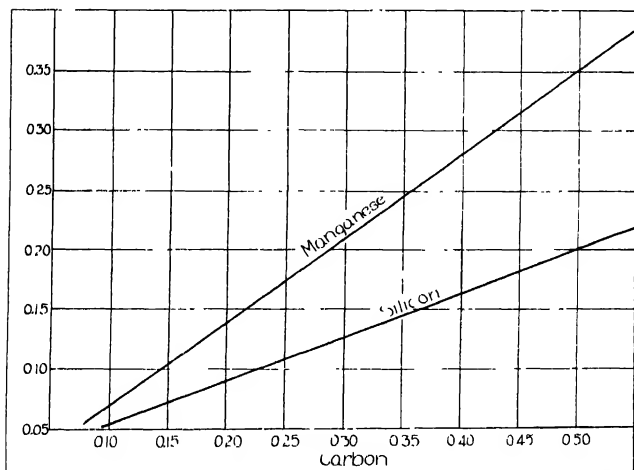


Fig 28—Variation in Manganese and Silicon With Acid Lined Furnace

formed the condition of the metal should be determined by slag and metal tests. A metal test will show the percentage of carbon either from fracture or analysis. Experience also has shown that a certain carbon content nearly always will be accompanied by the corresponding amounts of manganese and silicon, when melting scrap of a uniform type. This information gives certain data on the progress of the heat a high carbon meaning that

the manganese and silicon are up, and a low carbon the reverse. These comparative figures will change depending upon the size and character of scrap, rapidity of melting, slag volume, etc. Such a curve should be made for every furnace operating on this process to have at hand valuable information should occasion arise.

Fig. 28 shows such a curve plotted from several hundred heats covering the operation of a 3-ton furnace made by the Pittsburgh Electric Furnace Corp. This is based upon a charge consisting of approximately 25 per cent shop returns, the remainder being general boiler plate steel, the furnace melting 4 tons of metal in one hour, without any slag being added during this first period. While the figures shown vary slightly their average is close to analyzed tests and a correct enough to base additions upon when allowed a leeway of ten points.

#### *Slag Manipulation and Causes of Oxidation*

Assuming that a heat of low carbon steel for castings is being made, the finished metal to analyze approximately as follows: Carbon, 0.22 to 0.26 per cent; manganese, 0.60 to 0.70 per cent; and silicon, 0.25 to 0.30 per cent. A certain analysis of the molten bath will be found to give superior results on finishing. Such an analysis may be considered as a standard and any deviations taken care of during the reducing period. The best analysis of such a bath of steel is about 0.11 to 0.13 per cent carbon; 0.08 to 0.10 per cent manganese; and 0.05 to 0.07 per cent silicon. A heat of steel composed of scrap analyzing carbon 0.25, manganese 0.50 and silicon 0.15 per cent, and of average character, when melting down to the above analysis will be in excellent condition. There will be enough of the residual alloys to prevent any over oxidization, and yet the steel will be low enough to finish nicely within its limit.

Naturally, if every heat melts down at this analysis,

and similar additions of alloys are made, regular results will be obtained. Bringing the molten bath to a certain figure, is without a doubt the secret of regular analyses on the acid hearth. Appendix Tables 11, 12 and 13 are operating logs for hard, soft and medium steels made on the acid hearth. This melt down analysis is not an arbitrary figure, but is that obtained by averaging the melt down analyses of nearly a thousand heats, which were run under what might be considered perfect conditions. The next point is to determine what conditions will influence a change in melting to give either a higher or lower result than desired, and what will be necessary to overcome this difference.

#### *Correcting Low Figures*

Low figures on the melt down are shown when taking the first slag and metal test. The metal test is covered with splotches of oxide, and sparks heavily when poured into the chill test mold. As soon as the mold is filled, it generally gases so badly that the steel will be forced up out of the center of the test piece, leaving nothing but a shell. If it does not do this, it will bubble badly while solidifying, and the fractured test will consist of nothing but a net work of steel filled with gas holes, no crystalline structure being present. The slag taken on this test will be a dark black, thin and glassy, being brittle, and is known as a watery slag. Such conditions indicate poor metal, for an over oxidized condition results in a certain amount of oxide being dissolved in the metal. Often it is impossible to remove this oxide and later a cracked casting may result.

This condition is caused by an over supply of oxygen during the melt down which has *burned* out nearly all of the carbon, manganese, and silicon from the metal. The condition may arise from the following reasons:

This may have been caused by charging a larger

amount than usual of small sized, or dirty scrap. This is gross neglect. The melter, himself, should oversee or direct his next heat.

This may be caused by poor fitting doors, or by small pieces of scrap on the sills not permitting the doors to shut down tightly. The best method of overcoming this is to see that each door fits snug before the heat is started. Rake all pieces of metal from the door sills, and if a crack still remains fill it with a small amount of loose sand.

Any delay occurring after the metal has reached a red heat will lengthen the time in which the steel is exposed to oxidation. The result will be a heavy scaling of the metal, the oxide coming either from air entering through the door, or leaking in around the electrodes or through brick cracks in the roof. This delay may be caused by breaking an electrode, the power may go off, there may be trouble with the control apparatus, etc. To prevent any over oxidation, especially when a delay occurs after a pool is formed, a layer of sand should be thrown over the bath, and a light dusting of finely crushed coke added. This will help to cover the metal from any air drafts, the coke offering a protective screen.

In long continued delay, where it may be several hours before the current is again on, sand should not be added or it may solidify and prevent contact being made when the furnace again is started. In such an instance, it is best to give a light dusting with coke alone, the greater part of which will readily burn away without raising the carbon in the bath. In long delays of this kind, it is good practice to add ferromanganese figured to about 0.10 per cent, as soon as the current again is on.

To overcome an oxidized condition, the first step will be to give the entire bath a liberal dusting of coke. This will stop any further oxidation, and immediately will start reducing action on the slag. Ferromanganese may be added in sufficient amount to bring the manganese total in the metal to about 0.20 per cent. Slag now is added to the furnace, and the bath heated. Ordinarily, this treatment will overcome wildness in the steel, and the heat can be finished. However, the metal may have absorbed so much oxide that this treatment will not prove

sufficient. This will be determined by the action of the slag. If conditions progress in a satisfactory manner, the slag will turn from a dead black, and water slag, to one dark green in color. The slag will thicken, and lay quiet on the steel. If too much oxide is present, the slag, as soon as the metal heats up, will begin to foam, and will have the appearance of a heavy boil. The only thing to do in such a case is to tilt the furnace, and rake as much as possible of this slag off, and build another.

A high carbon test is evidenced through the metal lying quietly in the spoon, and giving a fairly sound test. The slag ordinarily will be thick, and of a medium green color. The flames from around the electrodes have the soft, luminous appearance of reduction, with a moderate amount of white or light brown vapor. If reducing conditions are severe, the furnace may even snow. Such a condition may be caused in the following ways:

1—Improper mixture of the charge, allows too great a percentage of high carbon, or shop scrap to the lighter metal. Too much scrap may be used with a large amount of adhering sand, such as ladle skulls or spilled metal, without the addition of ore to cut this reducing agent.

2—A piece of electrode may break off without being noticed, causing reducing conditions to commence.

3—The electrodes may dig causing an excess of slag to be on the metal, and reducing silicon so fast from the silica of this slag that all the oxide is used to again oxidize this silicon.

4—A large amount of slag making material may have been thrown in with the charge, without cognizance being taken of its already high percentage nature. An extra amount of patching material may have been applied to the furnace. This may dislodge and come up to combine with the slag.

Whatever causes such a condition, the result is the same. The composition is too high in carbon and the alloys, and if allowed to continue will result in the silicon



being so high in the finished metal as to make it unfit for use.

There is only one remedy for such a condition. Clean the metal rapidly of adhering slag, add ore, and boil until the metal is down to its standard condition, when a new slag may be added and the heat finished. In adding ore to boil the metal, the same care must be used as on basic operation. It is far better to add small amounts than it is to add too much. As this action of ore is endothermic, its action will not take place as soon as added, but will require several minutes until the bath has gained sufficient temperature for the action to proceed. This is an unknown fact to many melters, and after they add, say 50 pounds of ore, there is no immediate action, they come to the conclusion that the ore is held in the slag and make another addition. Then as soon as the ore does start to work they have a pretty boil on their hands, often severe enough to kick the metal and slag out of the furnace door.

#### *Ore May Retain Action*

Another point about adding ore is that it may still retain action after its immediate bubbling has ceased, due to the fact that part of the bath may be full of oxide, but too cold to give any action. Now if slag is added this oxide will begin an after boil when heated and the slag will have to be removed. To overcome such occurrences add the ore slowly in small sized portions. Then as soon as the boil begins, do not choke the furnace with ore, but allow each addition to get in its work before adding another. When the carbon is down approximately to its desired percentage, do not add alloys or slag, but allow the metal to heat and poke a rod in the bath to determine if any unmelted lumps remain. If so they must be melted clean before slag is added, if not the metal should be heated for several minutes until any loose por-

tions of oxide or ore have been dissipated, when the heat may be placed under its final slag.

A third point should be considered; that of slag volume. As oxide in high silicon metal tends to form slag in two ways, by combining with the silicon to form silica, and by its corrosive action on the walls, this must be taken into consideration before adding any slag or the final amount may prove to be too much. It must be considered that a highly oxidized slag is thin and watery, and it may look as though there is little slag on the metal. However, when this oxide is eliminated, and the slag begins to thicken, what may have appeared small is likely to prove a considerable amount.

At this particular point certain conditions exist. The metal is low in carbon, manganese, and silicon. It still is cold and due to oxide it is wild. What slag is on the bath is full of oxides of both iron and manganese, which causes the dark color. The steel is in no condition to pour, being of poor quality and too cold. This latter is easy to overcome by continuing the heating, but a steel heated to a high temperature under such oxidizing conditions would be of no use for steel castings as they would give the familiar appearance of a piece of cheese. Therefore, the first step is to eliminate the oxide before the temperature of the steel rises to the point where dissolved oxide will remain in solution. The first step is to add fresh slag in sufficient quantity to perform the desired operation.

For this purpose many materials are in common use. Old floor sand, crushed brick, or almost any form of a silicious material will prove satisfactory. This should be rather small in size, preferably of the same character as dry sand, and should be dry and free of any oxide in the form of rust, burned iron, etc. This material is spread carefully over the furnace, the exact amount being dictated by experience. The author has found about 8 scoops

or approximately 150 pounds to be enough for working a 4-ton heat.

After this slag has been in the furnace about 5 minutes the door should be opened and an inspection made. If this slag material has lumped, it must be rabbled, if not the doors can be closed and the metal heated.

At this time the flames issuing from around the electrodes will be rather sharp, and of a reddish blue color, but without any appreciable amount of smoke. However, as soon as this slag is added the flames will drop down to practically nothing, and dense white fumes will be emitted. As this slag melts and diffuses over the steel the white smoke gradually changes to a thin, yellowish white fume, accompanied by the familiar soft, luminous flames denoting the start of the reducing period. This condition also denotes a heating up of the metal, and a test should not be taken.

The metal at this time will be heavily charged with oxide, and will be rather cold. The slag should be a dark green in color, and of a medium consistency. If still thin, but green, more slag should be added. If the slag is still black no more slag should be added, but about 10 or 15 pounds of ferromanganese should be added, and a few small shovels of coke dusted over the slag. Ordinarily this will be sufficient to start the slag to working with its attendant reducing powers.

From this time tests should be taken with regularity every 4 or 5 minutes, both slag and metal being examined. As the bath heats and deoxidation proceeds this slag gradually will turn into a lighter green finally showing a greenish yellow color. When this color appears the slag should be rather thick and tough, and should string from the test spoon from the furnace. This is the final and absolute slag test. The metal at this time should be free from any reddish brown oxide spots on its surface, and should pour over the test spoon in a clear blue stream, with little

sparking. The test will not be absolutely sound, but should not contain any apparent blow holes on fracture

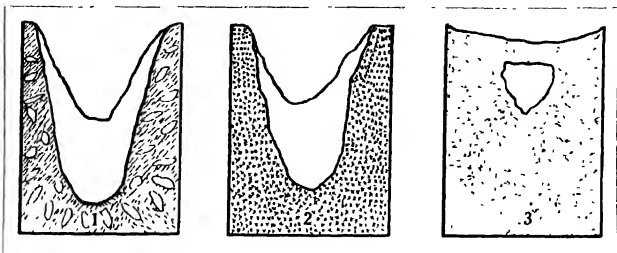


Fig. 29

#### No. 1 Overoxidized Metal

Carbon, manganese and silicon all under 0.070 per cent. Metal impregnated with oxide as shown by the gas holes. The metal has no apparent crystalline structure, the test having the appearance of tearing, rather than breaking, when fractured. Slag test accompanying such metal will be thin and watery, and of a glassy black color.

#### No. 2—Metal of Correct Composition

Carbon approximately 0.11 to 0.17 per cent; manganese, 0.08 to 0.20 per cent; silicon, 0.05 to 0.10 per cent. Metal around rim, when chilled, has a sound structure with a distinct crystalline appearance, the crystals being from medium to large in size. This test will bend before breaking, and often may show evidences of tearing. Slag accompanying such metal may be moderately thin, but usually will be a lighter color—a dark gray, or often a dark green. If black the slag will be more of the nature of lava, being rather dull, without much lustre. It will not resemble the brittle, glassy slag of overoxidation, but will be rather tough in character.

#### No. 3—Metal Coming Down Too High

Carbon, usually above 0.30 per cent; manganese ranging from 0.20 to 0.35; silicon, from 0.15 up, the latter depending largely on the carbon content. Metal will consist entirely of a crystalline structure, the size of the crystals depending upon the carbon content, and the rapidity of quenching. When broken it will snap with little impact from the hammer, often with a sharp snap. The slag on such a test will always be green, the degree of color depending upon the degree of reduction, and the volume of the slag body. The slag structure will depend upon the quantity present, and will range from one with a fair degree of brittleness to that resembling a finishing slag, being very tough and stringy.

having clear metal around its rim, where it has chilled against the mold.

If the above conditions exist the heat is ready to be brought to its final analysis and poured. However, certain other conditions may exist at this point, and the metal never should be poured under any but perfect conditions.

Often through the metal becoming over oxidized at this point the metal is beginning to heat and the slag is still black, and thin. A metal test taken will be wild, and even may foam up out of the test blocks. Ferromanganese and coke should be added as mentioned, and heating continued. If after heating for several minutes there is no change in its appearance and the metal is still wild, a small amount of additional slag material may be added, and well rabbled in. If this too is unsuccessful, the only procedure is to rake off this slag, and build another, first adding sufficient manganese to the metal to bring its content up to about 0.25 per cent. A dusting of coke is given the slag which will nearly always bring it around.

If there is insufficient slag body on the metal at this point it will be noticed by the slowness of heating, the metal seeming incapable of reaching its proper temperature. The metal tests will show favorable, and the slag will be of a medium green. More slag added quickly will change this condition to its proper state and the heat can be finished.

#### *Thick Slags are Deleterious*

Slag which is too thick gives a serious condition, especially if occurring while the temperature of the metal is rather low. The slag is thick and heavy, and the arc has difficulty in breaking as can be seen by its irregular actions. The furnace may even begin to *snow*. If this is detected at the start, a slag test should be taken and its condition noted. If the slag merely is lumped or viscous

due to a high silica content, a small amount of burned lime added quickly will bring it to proper condition. However, if the slag volume is too large, part of it must be raked off at once. If allowed to continue, the result will be a rapid reduction of silicon into the metal with the chance of having an off heat. The author has seen silicons analyze as high as 1.00 per cent when finished under such conditions.

It may be possible to have a perfect slag and still have *wild* metal. This may sound peculiar, but is explained by the fact that the slag itself is the main deoxidizer and operates by absorbing the oxide from the metal, bringing it to the surface, where it is removed by combining with carbon. The freed iron or manganese in the slag then combines with another charge of oxide and the process is repeated until the metal is clear. The reason for the metal being wild under these conditions is the fact that it has had insufficient time to perform its work on the metal. The solution is to hold the bath under this slag in a similar manner to holding steel under a carbide slag in the basic furnace. Oxide in the metal easily may be determined by observing its surface in the test spoon as taken from the furnace. If oxide is present small reddish brown spots will appear and disappear on the surface of the metal, the steel sparking when poured. If the bath is free from oxides the metal will have the familiar bluish appearance, its surface being mirror like in its freedom from spots.

The slag being of correct composition, and the metal being in a deoxidized condition, the next step is to bring it to a temperature high enough so that approximately 10 minutes more will be required to heat to pouring temperature. The present analysis of the metal is known, either by experience—or by actual analysis the latter always being preferable where possible.

As soon as this point is reached, it is time to recar-

bonize if necessary. If the carbon is correct, the manganese of the percentage desired is added in rather large lumps, being slightly moistened if the slag is thick, and allowed 5 minutes to diffuse thoroughly, when the heat is poured.

### *Methods of Recarburizing*

There are as many ways to recarbonize a heat of acid steel as of basic, but it must be remembered that time is an important consideration in this process. The steel cannot be held at this high temperature for any length of time without picking up silicon so that the addition of coal, coke, graphite, etc. and rabbling into the steel is unsatisfactory, due to the length of time necessary to perform this operation, and check its effectiveness by tests. Therefore, three main methods of adding the necessary carbon remain, namely: by using pig iron, carburite, or by immersing the electrodes in the bath with the current off.

Carburite is a mixture of iron and carbon containing a high percentage of the latter, and having a high enough specific gravity to sink into the metal. The only objection is the fact that small pieces might be held in the slag and its composition is so high in carbon that a small difference in weight would make a large difference in the metal analysis. For exact practice this eliminates this alloy.

Immersing the electrodes is common practice in many shops, but this shows carelessness. Many variables are encountered such as the size and character of the electrodes, the effective area exposed to the metal, the temperature of the metal, the volume and viscosity of the slag, and the present content of the metal. These make this practice unsafe. When the electrodes are lowered into the metal, they become coated with a varying amount of slag. A melter cannot tell these conditions and the result is that he fools himself into thinking that this con-

stitutes good practice by assuming that carbon added immediately before the pour will not have the chance to lower itself by reducing silicon. With electrodes at 6 or 7 cents a pound this will prove a rather expensive method of adding carbon, especially at the end of a year's time.

The one remaining recarbonizer, pig iron, is the best and cheapest agent for adding the desired carbon. The amount added is exact. The pig is so heavy that it naturally passes the slag and is all absorbed by the metal. It is cheap. These points constitute a great advantage. The main argument advanced against the use of pig is that after its addition the current must be kept on a sufficient length of time to heat it up to the pouring temperature. The objection here arises that under such high temperatures the carbon will tend to reduce the silicon, thus automatically lowering itself. The writer never has found this to be true on heats where the carbon content was under 0.30 per cent. On many heats, where the pig was added at least 20 minutes before the pour, the metal being heated high enough to pour 60 flasks, the carbon drop never amounted to over 0.03 per cent, and on many of these instances the difference might have been due more to error than to furnace conditions.

On extremely high carbon heats, for instance, 0.80 to 0.90 per cent carbon, where this amount of carbon constitutes a great part of the iron impurities this feature of reduction holds, and it is here advisable to use a different method, the best being the use of a higher percentage scrap, so that little carbon adjustment is required.

### *Silicon Lowered*

Often a heat may seem to be coming down perfectly, but as the temperature rises to the finishing point, it will be noticed that much silicon is being reduced. This will manifest itself by the silvery appearance of the metal in the spoon, and by its quick setting when poured into the



mold. The metal may be hot, yet will freeze as soon as it leaves the spoon. This often misleads melters, regarding the heat of their metal, and results either in pouring a cold heat or, one so hot that it actually welds with the sand of the molds. If the metal is hot enough to pour, the best thing to do is to tap at once, and change the silicon addition accordingly. The amount of this change can be learned only by experience, but approximations can be given. If the ordinary silicon addition, made to metal where there is no apparent pick up, is 0.20 per cent, this should be cut in half if the metal is held under the above conditions for 5 minutes. If held for 10 minutes no silicon should be added. Another method is to add the manganese and take a test in a sand mold. If the metal sets nicely there will be no silicon required, any additions being based upon the action of the metal in the sand. Under the conditions of extremely hot metal used for small casting work, this pick up will approximate 0.02 per cent per minute, where the refining current is about 120 volts.

If the metal still is too cold to pour, the best remedy is to rake off as much as possible of the slag, and add enough ore to cut this silicon. A small amount of lime will keep the slag fluid for the remainder of the heat without any further danger of such reduction. Ordinarily this reduction will not take place until the metal becomes hot, and then will amount to little if this silica content of the slag is kept below 55 per cent. When this silica content passes 55 per cent there is nothing to hold the silica in combination, and reduction is the natural action. Often lime added at the first signs of silicon in the iron will furnish a base to hold this excess silica in combination without any reduction.

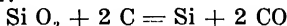
This reduction of silica occurs only in the presence of heavy slags and is enhanced by the presence of coke on the bath. Consequently, when coke is used to start

reduction, care must be taken not to add it in excess or it may result in trouble later. In cases where no coke is used and reduction occurs, the carbon necessary for this action comes from the electrodes. Another theory has been advanced by B. Yaneske regarding this phenomenon. In a paper read before the British Iron and Steel institute in 1913 he has the following to say in reference to the reduction of silica from acid slags:

"Spoon samples of metal also are taken periodically and if a reasonable amount of stewing has been allowed after each ore addition with the bath kept consistently at as high a temperature as the refractories will stand, the samples will become more or less riddled with holes and the slag covering the metal is seen to rise in the spoon owing to the escape of gas. This is a true indication that a stage has been reached when the slag has become so highly silicious that there is an excess of silica above that required to satisfy the reduced amount of basic oxides present. Consequently, this excess silica once freed from combination with the basic oxides, begins to be reduced by the iron, the silicon passing into the metal and the oxygen liberated from the silica perforating the metal samples, thus:



"In the furnace bath, where the slag is only in contact with the surface of the molten metal, the oxygen will escape from the silica reduced without passing through the metal. The author here ventures to disagree with several authorities who have stated that it is the carbon which effects the reduction of the silica according to the equation:



"It is the author's opinion that iron must be a far more powerful reducing agent than carbon, for iron is always present in great excess, and it is an established fact that oxygen has a greater affinity for silicon than for carbon in the open hearth furnace (also electric under general operating conditions. L. J. B.) this being the basis of the acid process, therefore it seems highly improbable that carbon will displace silicon from combination with oxygen at the furnace temperature. For

carbon to reduce silica according to the previous equation, it is easily calculated that there must be a loss of 0.06 per cent carbon from the metal for each gain of 0.07 per cent silicon from the slag, and yet analyses have proved to the author that the reduction of silica frequently has occurred to such an extent that the percentage of silicon passed into the metal from the slag has exceeded 0.10 per cent while the carbon in the bath has not fallen more than 0.03 per cent. In fact he always has found the loss of carbon to be less than normal whenever there has been a considerable gain of silicon from the slag, for whatever be the reaction it is obvious that for the silica to be reduced at all, the amount of oxygen dissolved in the metal must have reached a minimum. Therefore, it can only be by atmospheric oxidation from gases that the carbon is removed when the metal is free from the dissolved iron oxide. Iron in the absence of dissolved oxygen is also liable to reduce some of the silica of the hearth, particularly when the hearth has been newly sanded, the silicon passing into the metal being subsequently oxidized by the further addition of iron ore, thus causing an increase in the silica content of the slag."

While it is not the purpose of the author to argue upon the relative merits of differing theories it must be here stated that the theory advanced by Mr. Yaneske, while not being the accepted one, is in a general way correct. While we cannot know exactly whether or not it is iron or carbon which causes the reduction, an experiment proving the above theory will be explained.

Melt a heat of steel, and work exactly as for an ordinary soft casting heat. Keep the slag in a fluid condition and heat up to a high temperature. As long as this slag is kept fluid, by additions of lime, there will be no silicon pick up, no matter how high the bath is heated, or how long the metal is held at such a temperature. Now still keeping the slag fluid add carbon to the slag in the form of coke dust. The carbon in the metal will increase slightly, but as long as the slag is kept in

a fluid condition there will be no increase in silicon. Metal tests taken under these conditions always will show fairly sound, and will not rise in a chill mold. When broken they will show sound metal around the rim, with no evidence of gas holes. The slag will be a perfect color, the familiar light yellowish green. If the heat is poured with silicon added in the ladle, the steel will be perfect.

Now, without allowing any oxidizing influence to enter the furnace, allow the power to be shut off long enough to permit the metal to chill slightly so that there cannot be any question as regards a higher temperature causing the reduction, quickly open the doors and spread enough sand over the slag to thicken it to a rather heavy condition, but not to a special or unusual thickness. Turn the current on and quickly note the silicon pick up. The metal tests will begin to rise in the molds, and upon being broken will show the familiar network of blow or gas holes, the slag being of exactly the same color, but considerably thicker. Now there is no way to explain this but to assume that the oxygen of the silica has contaminated the metal. If manganese is added here, the steel again will show a sound condition.

This reduction of silica can be accepted as coming under the following phases:

1—Reduction from the silicious hearth material, the action being caused by either iron or carbon from the metal itself.

2—Reduction due to increased silica content of the slags. This can be eliminated in part by a judicious use of lime.

3—Reduction from the silica of the slag by carbon, coming either from the electrodes, or from coke added to the furnace.

4—Reduction due to increased slag temperature.

It will be found that the reduction of silica always is the heaviest on the first few heats from a newly lined furnace, and is readily explained by the increased slag

volume caused by a first running or spalling of the fresh brick.

### *Effect of Acid Lining on Slag*

In making steel on the acid hearth reactions are encountered similar to those of the basic furnace. The initial charge of scrap metal, more or less oxidized, containing varying percentages of carbon, manganese, silicon, phosphorus and sulphur is similar in both cases. However, a new condition, that of the acid hearth, which is readily attacked by the oxides of both iron and manganese, confronts the melter.

As soon as the current is thrown on, the metal begins to melt, and drips to the bottom of the furnace. The first reactions begin here, the phosphorus, silicon and manganese in the metal combining with the oxygen of the rust to form their respective oxides. The acid nature of the slag reduces the phosphoric oxides back into the metal, giving rise to an endless chain of reactions. The iron and manganese oxides combine with the silica from dirt on the metal, and from the silica formed by the oxidation of the silicon from the metal. This forms the first slag body, which at first is a thin watery mixture consisting of probably 50 per cent oxides. As soon as a small pool is formed these oxides begin to attack the hearth and side walls to obtain sufficient silica to hold themselves in combination. During this melting down the carbon also is removed as the gas or carbon monoxide. A small amount of sulphur is burned out, probably in the form of another gas, sulphur dioxide. This latter action depends greatly on the percentage of sulphur in the steel, but ordinarily the sulphur will drop approximately 10 per cent.

As soon as the slag body obtains sufficient oxides and silica to give it an equilibrium, its corrosive action ceases, and its further action on the banks stops. Attacking the walls is strictly a chemical occurrence de-

pending entirely upon the amount of oxides in the metal. In a properly balanced heat, these reactions will occur in proper sequence, and at their termination the steel will be left in perfect condition.

However, if an excess of the alloys exists in the metal, the slag body will be greatly enlarged allowing other reactions to occur, the principal one being the change from the oxidizing state to that of reduction, caused by the supply of oxides being used. This reaction can be prolonged only by the addition of further oxide such as ore which commonly is used. If there is an oversupply of oxides, the natural result is that they rob the metal of every possible portion of alloys, with which to form a balanced state. The result is that their percentages will be extremely low, the remainder of the oxide present dissolving in the metal, causing extreme wildness.

### *Reduction of Oxides*

These are the varying conditions on the melt down. However, as soon as the furnace is placed on a reducing basis, by adding an excess of silica, any free oxide is absorbed immediately. The reduction of silicon begins by any of the four phases, the result being that the oxides of iron and manganese are reduced to the point where there is perfect reducing equilibrium. In other words, all the oxides present are in combination with the proper proportions of iron and manganese to form a stable slag, in which state they are negative as far as any oxidizing action goes, any excess oxides being reduced by the nascent silicon, their metals passing into the steel. As this continues, the metal becomes free from gas, and the slag changes from the dark oxide color to the light greenish color indicating perfect freedom from excess oxides.

If at this point the speed of the reactions has been

so controlled that all reaction is accomplished at the time the metal reaches the pouring point, the heat can be poured. If the temperature of the metal has lagged, the slag and metal must be treated to prevent this fur-

Table XXIV

CHEMICAL REACTIONS IN ACID ELECTRIC FURNACE PRACTICE

1.  $\text{Fe}_2\text{O}_3 + \text{Fe} = 3 \text{FeO}$  (Presence of excess molten iron)
  2.  $2 \text{Fe}_3\text{P} + 8 \text{FeO} = (\text{FeO})_3\text{P}_2\text{O}_5 + 11 \text{Fe}$
  3.  $2 (\text{FeO})_3\text{P}_2\text{O}_5 + 5 \text{Si} = 6 \text{FeO} + 5 \text{SiO}_2$  (Presence of acid slag)
  4.  $2 \text{Mn} + \text{O}_2 = 2 \text{MnO}$  } From excess oxygen
  5.  $\text{Si} + \text{O}_2 = \text{SiO}_2$  }
  6.  $\text{S} + \text{O}_2 = \text{SO}_2$  (Weak reaction)
  7.  $2 \text{Fe} + \text{SiO}_2 = \text{Si} + 2 \text{FeO}$  (From hearth and walls)
  8.  $\text{Si} + \text{O}_2 = \text{SiO}_2$  (To form slag)
  9.  $\text{FeO} + \text{MnO} + 2 \text{SiO}_2 = \text{FeSiO}_3 + \text{MnSiO}_3$  (Stable slag)
- Leaving Manganese  $\pm 0.08$  per cent and Silicon  $\pm 0.05$  per cent in the metal.

If Over Oxidized

10.  $2 \text{Mn} + \text{O}_2 = 2 \text{MnO}$  }
  11.  $2 \text{Fe} + \text{O}_2 = 2 \text{FeO}$  } To almost absolute removal of sili-
  12.  $\text{Si} + \text{O}_2 = \text{SiO}_2$  } con and manganese from the metal.
- If slag becomes too heavy or premature reduction starts.
13.  $\text{SiO}_2 + 2 \text{Fe} = 2 \text{FeO} + \text{Si}$
  14.  $\text{SiO}_2 + 2 \text{C} = \text{Si} + 2 \text{CO}$
  15.  $\text{FeO} + \text{C} = \text{Fe} + \text{CO}$
  16.  $\text{MnO} + \text{C} = \text{Mn} + \text{CO}$

Finishing

17.  $\text{SiO}_2 + 2 \text{C} = \text{Si} + 2 \text{CO}$
18.  $\text{SiO}_2 + 2 \text{Fe} = \text{Si} + 2 \text{FeO}$
19.  $\text{Si} + 2 \text{FeO} = \text{SiO}_2 + 2 \text{Fe}$
20.  $\text{Si} + 2 \text{MnO} = \text{SiO}_2 + 2 \text{Mn}$

Iron and manganese oxides will be reduced above that amount required to form a stable slag with silica.

If reduction is too heavy

21.  $\text{SiO}_2 + 2 \text{C} = \text{Si} + 2 \text{CO}$
22.  $\text{SiO}_2 + \text{Fe} = \text{FeSi} + \text{O}_2$

Silicon reduced into metal.

If lime is used

23.  $\text{SiO}_2 + 2 \text{C} + \text{CaO} = \text{SiO}_2 \cdot \text{CaO} + 2 \text{C}$
24.  $\text{SiO}_2 + 2 \text{Fe} + \text{CaO} = \text{SiO}_2 \cdot \text{CaO} + 2 \text{Fe}$

Carbon and iron made inactive—the silica having a greater affinity for lime than for reduction.

ther reduction of silicon, the remedies being the addition of ore or lime, or the freeing of the bath of enough slag to so lower the volume present that reduction ceases.

If the slag is behind the metal in its actions, further

additions of sand may be required, or carbon, ferrosilicon, or ferromanganese may become necessary.

The complete chemical reactions arranged in their proper sequence as far as possible, and being segregated for each set of conditions is given in Table XXIV.

While lime may offer a solution to certain problems met in acid steel practice, its use is not necessary, except under unusual conditions, although many shops operating under excellent practice, use it constantly. If the heats are proportioned properly at the start, and the volume of the final slag is added with judgment, there will be no necessity for thinning the slags, for the reduction of the slag will proceed directly in conjunction with the heating of the metal. Consequently, at the time when the slag begins to become pasty and the reduction of silicon becomes apparent the metal is hot enough to pour. Of course, conditions arise where the pasty condition of the slag precedes the finishing, and if satisfactory metal is to be poured the slag must be thinned to permit the gases to pass up and through.

A slag of the proper body, during the final period of the heat, has a bubbling, or churning appearance, often with a distinct gas passage, the gas burning at the slag surface with a series of bright, sharp flames. As the spoon is inserted into the bath for a test, the slag rolls up around the handle, in a manner similar to the foaming of a basic carbide slag. Any slag in such a condition does not need any treatment, but rapidly will reduce any free oxides, and leave the metal in its desired condition.

A slag which requires lime for thinning, and to take care of the excess silica, appears heavy, and often a considerable amount of slag will be withdrawn from the furnace when a test is taken. The slag lies heavy on the metal, and difficulty is experienced in forcing the spoon through to the steel. Such a slag always is a nice color, and tough in texture, but unless a high sili-



con is desired should be immediately diluted. Another bad feature of such a slag is its inability to clear itself during pouring with the result that part is left in the furnace building up the hearth, often to a point where it must be chipped and cut back to shape.

The amount of lime in a standard slag varies from about 8 to 30 per cent, depending upon the operator, and the practice followed. Naturally, a minimum of this compound should be used as its action on the roof and walls is severe, both from its vapors and from solid particles impinging on the refractories. If burned lime is used it should be mixed with sufficient sand to avoid as far as possible this powdery substance being deflected against the roof and walls. Limerock in small pieces is satisfactory, and does not have these objectionable features. If added directly under the arcs the heat quickly will decompose the carbonate, and the force of the arc will diffuse the lime through the slag. As the lime in slags increases, the color changes from the light green to more of a porcelain grey green, and upon further additions may even give a slag powdering in the air. With slags of over 25 per cent lime, difficulty is experienced in obtaining proper conditions for silicon reduction, due to the fact that the silica is so firmly held by the lime that its reduction in the furnace is hindered.

#### *Some Reduction of Sulphur in the Acid Process*

That the sulphur content of steel cannot be lowered on the acid hearth has appeared in print so often that it is fast being accepted as an absolute fact, although there is no ground for such a statement. That there is no reduction analagous to basic operation is well known, but that there is an appreciable lowering of the sulphur content also is true.

While the reaction causing this is at present unknown, it is probable the culmination of several separate

chemical actions. One of these probably is by the direct action of the oxides with the sulphur in the steel, the product being the gas, sulphur dioxide. The reaction may be similar to that of gray iron, where manganese combines with sulphur to form the sulphide, which rising to the surface is partly oxidized. The remainder of the manganese passes back to the steel. Another possibility

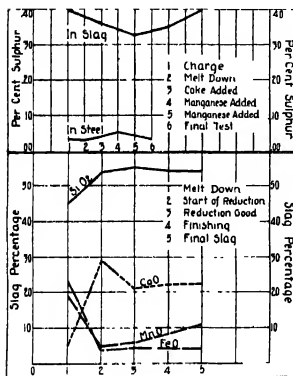


Fig. 30

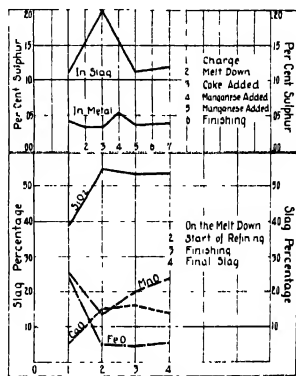


Fig. 31

Fig. 30—Analysis of Sulphur in Slag and in Steel and Comparative Relations of Other Elements. Fig. 31—Percentages of Sulphur in Steel and Slag and Analyses of Other Elements During the Heat

is that the sulphur is lowered by combining as the volatile sulphur silicide, and passes from the furnace in the form of vapor.

During the past few years, data have been circulated covering special slags with the ability rapidly to lower the sulphur content. Most of these make use of a high lime content, and are naturally impracticable.

Figs. 30 and 31 show the changes occurring in two acid furnace slags, from oxidizing to finishing. The curves for sulphur contents of both metal and slag also are

given. The sulphur pick up when coke was added, and its consequent lowering during finishing, show conclusively that a certain amount of sulphur is eliminated, amounting in certain cases to as much as 25 to 50 per cent of its initial content, although not over 10 or 15 per cent could be assumed to be the average reduction. The greatest amount of sulphur tends to be eliminated under low temperature conditions, and in cases where the iron oxide content of the slag is rather low.

### *Addition of Alloys*

Alloys may be added to the acid furnace in as many different ways as in the basic, although the use of ladle additions is more common to the former process, due the higher temperature of the metal poured, allowing a better diffusion in the steel. Manganese should be added at least three minutes before the pour, being placed in the furnace in lumps the size of the fist, and being thrown directly under the electrodes if possible. Under conditions of a heavy or viscous slag these lumps should be slightly moistened so that the sudden emission of steam will throw the slag aside, and allow the alloy to enter the metal directly. If a certain set time, say between three and four minutes, is allowed, any losses will usually run standard and a certain allowance can be made in making up the percentage.

In adding manganese for close analysis, a chemical test should be made as soon as reduction begins, and the alloy calculated on that basis. It also must be remembered that the efficiency of the manganese will vary with differing furnace conditions such as the temperature of the metal, volume and condition of the slag, percentage of lime in the slag, amount added, etc. These differences can be learned only by experience and observation, their exactitude changing for different classes of scrap, and for differences in finishing voltage.

In bringing the silicon to specification three main methods are in use. These include:

Allowing a heavy slag to build itself and permitting the silicon to reduce into the metal until the desired percentage is reached.

Finishing the metal in a deoxidized condition and adding the ferrosilicon in lumps to the furnace itself.

Finishing as in the previous method, but adding the

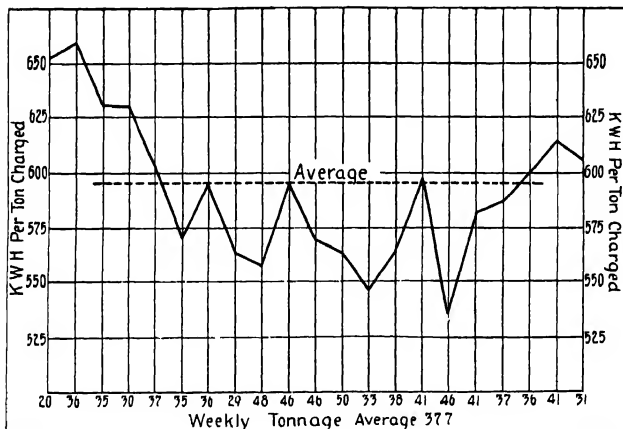


Fig. 32—Power Consumption in a New Three-Ton Furnace Making Steel for Small Castings—Note Decline in Power as Furnace Crew Becomes Efficient

silicon to the ladle in pieces from the size of wheat to pea size.

Of the three methods there is no argument as to the first giving a metal of superior quality. In this instance all the silicon is in the nascent condition, in which state it is an extremely powerful deoxidizer. Naturally the metal made under such circumstances is as sound as it is possible for steel to be made under any present method. The only objection to this process is its irregularity due to varying conditions of reduction, often re-

sulting in metal of a widely changing composition. However, it is possible, by using the greatest of care and observation, to pour regular metal by this method, but its use is recommended only for operators with sufficient skill and experience to understand the varying conditions of temperature and slags. The author uses this method for all casting work requiring high tests, and on one certain specification covering approximately 100 heats only missed two silicon percentages, and then by such small fractions that the metal proved thoroughly satisfactory.

The second and third methods are on a par as regards the quality of the metal, and the ladle addition is preferred except on heats where cold pouring is used. When the silicon is added to the furnace there is always the possibility that part may be absorbed by the slag, leaving insufficient to alloy the metal. This is especially true of heats where the slag is rather thin, or in heats where an unforeseen delay holds up pouring for several minutes. In adding to the ladle, the silicon is placed in a bag, and thrown directly into the stream when the ladle is about one-third full. The alloy being small size, and of a much lower melting point than the steel it is melted quickly, the churning of the metal diffusing it throughout the steel. If the ladle is held for several minutes to allow any deoxidation products to come to the surface, first class metal is assured.

As the general pick up of silicon during reduction is about 0.05 to 0.10 per cent, without its increase becoming apparent, the percentage in the metal can be figured as 0.10 to 0.15 per cent, requiring an addition in the ladle of only 0.15 to 0.20 per cent. As this amounts to only 6 to 8 pounds per ton of the 50 per cent alloy, it is apparent how easily this addition will combine. The author has examined a great number of heats made in this manner for differences in composition, by taking tests at vary-

ing periods of the pouring, but seldom found any segregation of silicon, although the percentage of silicon in a hot heat always will increase, due to the reducing effect of the metal on the slag and the brick of the ladle. As this amounts to only a few hundredths of one per cent it is negligible as regards any effect on the steel itself.

### *The Effect of Silicon*

While there is constant argument regarding the effects of silicon on casting steel, the writer has been unable to find such effects. While the generally accepted range of silicon in steel castings is from 0.25 to 0.35 per cent, no great change was found in the strength, elongation, or general casting characteristics on steel pouring as high as 0.70 or 0.80 per cent silicon. On certain types of castings from 0.50 to 0.60 per cent silicon is specified regularly. We hear a great deal about castings cracking if poured with high silicon metal, especially if the temperature of the steel is high. Heats have been poured where from 55 to 60 molds were cast from 3 tons of metal, the silicon being in excess of 0.60 per cent, and no cracks caused by the composition of the metal were found. If the method of gating and heading the castings is carefully examined, the fault in the great majority of cases will be found in insufficient allowance being made for shrinkage strains, or some part binding, and allowing the metal to tear while shrinking.

While certain figures are often shown as expressing a set ratio of melting to refining on certain types of furnace, these are at the best only rough approximations. To determine if such a figure could be consistently obtained, close observations were made on a number of heats as melted in a three-ton furnace. With two heats a day, refining required 25 to 40 per cent of the current consumed in melting.

## MANGANESE STEEL

**M**ANGANESE steel falls among the true alloy steels, but the rapid increase in its manufacture during the past few years has made it a steel of such importance that data covering this metal should be offered independently.

Manganese steel first was brought to light in England about the year 1888, through an extensive set of experiments made in the plant of the Hadfields, Ltd., Sheffield.

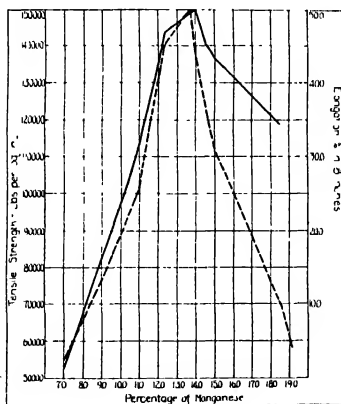


Fig. 33—Influence of the Variation in Manganese Upon the Physical Properties of Steel

These demonstrated that manganese, added to steel in large amounts, conferred upon the metal unusual properties, differing widely from those accepted as standard. The first castings of manganese steel were made in this country in 1892. Since that time the manufacture of

this class of castings has increased until the present capacity of this country is approximately 70,000 tons a year.

This metal, due to its peculiar properties requires strict specialization. Probably four to five companies make at least 95 per cent of the tonnage used in America. The difficulties attending the commercial manufacture of this steel are many, and are not generally understood by the foundryman. Differing greatly in its properties from ordinary carbon steel, the attempt to enter this field by inexperienced operators has been the prime cause of several failures in the steel casting industry.

Manganese steel, properly made and treated, offers a metal of unusual characteristics. Its main point of superiority over plain steel is in its great toughness and resistance to wear. As a consequence, it is finding wide use for parts subject to shock or in castings for uses where resistance to abrasion is needed. Some of its most prominent uses are in ball mills, brick making machinery, cement, clay and miscellaneous crushing mills, dredge boat and bucket parts, crane, truck, gear and sheave wheels and in frogs and rails.

While the greater portion of the tonnage made is used in the form of castings, it also finds wide use in forged or rolled products under which treatment it shows an increase in strength similar to carbon steel. Manganese steel, when cast and treated, has the following properties:

Tensile strength, lbs. per sq. in.....	100,000 to 110,000
Elastic limit, lbs. per sq. in.....	50,000 to 55,000
Elongation, per cent in in. ....	35 to 40
Reduction of area, per cent.....	35 to 40
Brinell hardness .....	180 to 200
Scleroscope .....	40 to 50

The influence of the percentage of manganese on the physical properties is shown in Fig. 33. Naturally, a steel



of such a character finds wide use. Great amounts are shipped to all parts of the world, from the gold mines of Alaska to the great dredges of South Africa. The great work of building the Panama canal was made possible by the use of manganese steel.

Manganese steel is practically non-magnetic, and for this reason finds wide use in the protecting plates used for electric magnets. Most of the steel parts on the famous North Pole, non-magnetic ship, were made of this steel.

While a manganese steel is extremely resistant to wear it does not owe this property to its hardness, as is shown by tests made on both the brinell meter and the scleroscope. The toughness appears to be due more to its great molecular cohesion, causing the particles to flow rather than tear loose from each other. Its hardness is lower on the outer skin due to oxidation of carbon.

Until the past few years, manganese steel was made from converter metal according to the method first pursued by Hadfields. A low phosphorus, low sulphur pig iron was used in the cupolas, this iron being blown dead in the converter. To this low carbon steel, ferromanganese was added in the molten condition in sufficient amount to give the desired percentage to the steel, this figure ranging from 11 to 13 per cent manganese. The steel was blown as hot as possible, and only given a few minutes in the ladle to mix before pouring. Naturally, this steel was of a quality similar to ordinary converter steel regarding the amount of dissolved oxide, carbide conditions, etc.

The manganese was melted either in a crucible or in a special cupola, the crucible being preferable due to the lower loss of manganese entailed in melting. While manganese steel of good quality was made by this method certain disadvantages were encountered, the most important being the difficulty in remelting the old heads, gates,

spill, ladle skulls, etc. For this purpose air furnaces were used similar to the modern open-hearth furnace, but without any system of regeneration. While such furnaces proved capable of melting the steel in a satisfactory manner, this process resulted in a further loss of manganese by metal shrinkage which allowed the carbon percentages to raise the figures higher than desired. This resulted in metal of more or less irregular composition, and for a long time many purchasers refused to buy manganese steel made from old scrap. This naturally threw a heavy burden on the manufacturer to get rid of his old shop scrap, and many hundred tons of this steel was piled away, subject to the discovery of a practical method of reclaiming this waste material.

### *Enter the Electric Furnace*

When the electric furnace first began to assume prominence in the manufacture of steel castings, it was hailed as the cure-all of manganese steel making. Experiments naturally followed but at first, due to the lack of experience of electric furnace melters, results were poor. The same also was true in making the common grades of carbon steel castings during the early days. However, as time passed the electric furnace proved itself and manganese steel entered upon a new era. In 1918 several electric furnace installations were making manganese steel along with their ordinary grades of castings. In that year the American Manganese Steel Co., one of the pioneers of the industry in this country, placed in operation a new shop on the Pacific Coast using the basic electric furnace exclusively. From their data of the operation of this shop, it was seen that this method of manufacture was by far the most logical, these facts resulting in a complete change to the electric furnace in all the company's plants. Since that date there have been

several other installations expressly intended for making this metal.

If manganese steel, as made in the converter, was good metal the castings as made in the basic electric furnace might be well considered as much superior, due to the great advantages of the latter process of manu-

Table XXV

## THERMAL EFFICIENCY OF FURNACE ON MANGANESE STEEL

Using following formula:

Weight of steel in Kg X specific heat, latent heat of fusion

Kw Hr used X calories per Kw. Hr.

With 20 as latent heat of fusion, 470 as specific heat of steel; 600 as specific heat of basic slag, slag equals one-tenth of steel by weight; and 1 Kw. Hr. equals 860 calories. While 335 to 350 as specific heat for steel, and 535 for slag would probably have been more correct, the figures given were used due to the extreme temperatures to which the metal and slag are heated in pouring these heats for small sized castings. The following values were obtained.

	Per cent
Thermal efficiency of furnace	53.0
Total heat utilized in furnace	59.5
Total heat in steel	53.0
In slag	6.5
In cooling rings	2.55
Electrode holders	1.92
Transformers	1.23
Overcoming cold furnace, and radiation	34.70
Losses in cooling water on the roof rings, electrode holders, and transformers were obtained as follows:	

	Degree C.
Water to transformer	19.8
To holders	22.5
From No. 1 holder	26.3
From No. 3 holder	27.3

Temperature could not be obtained on No. 2 holder due to a drain pipe being in the way.

	Degree C
From No. 1 ring	31.2
From No. 2 ring	32.7
From No. 3 ring	32.9
No. 1 ring.	1 liter water in 4½ sec., or 14 Kg per min.
No. 2 ring ..	1 liter water in 4 sec., or 15 Kg per min
No. 3 ring	1 liter water in 4½ sec., or 14 kg per min
Total ..	43 Kg per min

## Transformer

(Temp water to holders -- temp water to transformers) X total kilograms equals calories per min.

(22 — 19.8) X 43 = 116 calories per min

## Holders

(Temp. from holders — temp to holders) X kg equals calories per min.

No. 1 (23.6 — 22.5) X 14 = 53 cal per min.

No. 2 (averaged) = 60 cal. per min

No. 3 (27.3 — 22.5) X 14 = 67 cal. per min

Total . . . . . 180 cal. per min.

Rings			
(Temp. from rings -- temp from holder) X kg equals cal per min			
No 1 ring (31.2 -- 26.3) X 14	=	69 cal per min	
No. 2 ring (32.7 -- 22.5) X 15	=	93 cal. per min	
No 3 ring (32.9 -- 27.3) X 14	=	78 cal. per min	

Total	240 cal per min.		
Transformer	116 X 60	=	8 Kw Hr
	860		
Holders:	180 X 60	=	12 Kw Hr
	860		
Rings	240 X 60	=	16.6 Kw. Hr.
	860		

Total 36.6 Kw Hr  
 4000 amp X 101 volts X 0.90 power factor X 1.74 = 650 Kw

Summary		
Transformer loss	$\frac{8}{650}$	= 1.23 per cent
	12.5	
Holder loss.	$\frac{650}{650}$	= 1.93 per cent
	16.6	
Ring loss:	$\frac{650}{650}$	= 2.53 per cent
Total water loss		= 5.70 per cent

facture. The thermal efficiency of an electric furnace melting manganese steel is given in Table XXV.

#### *Basic Furnace Offers a Minimum Loss*

The basic electric furnace offers a satisfactory solution to every problem met in converter practice. The first of these is its power of absolute deoxidation. In the electric furnace this is effected under a heavy lime slag, and offers a minimum of loss of the costly alloy, manganese. The second is the ability to hold the metal for almost indefinite periods without excessive changes in composition, making it possible always to obtain regular analyses, as the metal may be satisfactorily held awaiting the chemist's verdict. The third point is that of being able to control the temperature closely without resorting to holding in the ladle. The latter practice is likely to contaminate the metal by the formation of slag, caused by its corrosive action on the refractories of the ladles. The

fourth and greatest point is its ability to make excellent metal by remelting old manganese steel scrap, without any appreciable loss of the alloy.

When the first manganese steel was made in the electric furnace, the furnace was lined in the standard manner, with a silica roof, and with common magnesite brick up above the slag line. The hearth was made of burned in magnesite, and both magnesite and dolomite were used for patching purposes. It soon was found that this latter material was not at all satisfactory for patching. While it proved acceptable during the steady operations over a week's run, it always tended to disintegrate over the Sunday shutdown. This deposited a lot of loose material on the hearth which always tended to give trouble on the first heat of the week, by giving a high magnesia content in the slag, with its attendant high viscosity and difficulty in clearing. Furthermore, where this patching dropped it left holes, and voids, with more hearth trouble than should have been encountered. As soon as a good grade of prepared magnesite was used this trouble was eliminated.

#### *Method of Lining Furnace*

With silica side walls, trouble was experienced by the metal splashing against the banks, and rapidly eroding the silica brick, especially opposite the arcs where the walls were the hottest. This resulted in shutting down the furnace frequently to reline, the customary procedure being to repair the furnace over the week end, this being done every two weeks, and often after only a week's operation. Consequently, this proved to be rather expensive and steps were taken to find some refractory which would stand up under the severe service imposed. After trials of miscellaneous refractories a metal encased brick was found to solve the problem. While the first cost was considerably higher, it was found that such a lining

would stand up for from 6 to 8 weeks operation, and then a large part of the brick ends could be used again. Since that time this method of lining the furnaces has been standard.

Since adopting magnesite lining, better results have been obtained from the slags. Formerly, trouble was experienced with silica running into the slags from the walls, and so contaminating them that they were cleared with great difficulty. With no silica present, outside of the roof, heavier lime slags with their greater basicity, and consequent better alloy reclaiming facilities can be used. It is found that there is a considerable saving in time necessary to bring the slag to carbide conditions. Also, it is found that these heavier lime slags cut down the manganese loss when remelting old shop returns.

### *Melting Processes Available*

Disregarding for the present the remelting of manganese steel scrap, four choices of a melting process are available. These are:

1. The metallic charge of soft steel scrap can be melted under an oxidizing slag, the slag removed, a second slag added, and cleared under heavy reducing conditions, exactly as if a heat of carbon steel was being made. When the slag has reached its proper carbide condition, and powders upon exposure to the air, the ferromanganese can be added in lots of several hundred pounds at a time, the bath brought to its proper temperature and tapped.

2. The heat can be run as mentioned but adding the manganese immediately after slagging off, then adding the final slag and finishing.

3. The heat can be melted, the manganese added, and the steel finished under its first slag.

4. The ferromanganese can be added with the charge, and the steel finished under one slag.

While the first two methods often are used, and prove to be satisfactory, there are two main objections to their continued use. First, there is a direct loss of at

least 0.05 per cent manganese consisting of the alloy combined in the slag as the oxide, which is wasted when run from the furnace. Further, approximately double the amount of slag making materials—lime, spar, and sand—are required. This amounts to a considerable item in a year's time.

The fourth method seldom is used, it being too dangerous for consistent operations. While the amount of manganese lost could be kept low by using heavy lime slags, there always is the danger of carbon being picked up in undue proportion, usually by an electrode breaking off. Naturally there could be no lowering of the carbon without first cutting down the manganese, and the heat would have to be cast into a low grade product or scrapped.

Consequently, the third method is finding the widest use, especially in shops where manganese steel is the main product. This method offers a distinct saving in that the manganese in the raw scrap is largely recovered from the slag when placed under reducing conditions. While this only amounts to a few tenths of one per cent, the saving in ferromanganese over any length of time constitutes an important item.

### *The One Slag Process*

The furnace is charged in exactly the same manner in making a heat of low carbon steel, the scrap being arranged for economical melting, and no ore being added, unless there is a good reason to believe that the analysis of the charge is such as to give a high carbon on the melt down. No lime is added with the charge for the same reason as given before—the great tendency to raise the hearth level.

In making up the charge it must be remembered that the later manganese addition will constitute approxi-

mately one-sixth of the initial weight of scrap charged, so that only about six-sevenths of the weight of metal desired must be charged at the start.

As soon as the charge begins to melt, and a slight pool of metal is formed on the hearth, the lime can be added. At this point only enough lime should be added to furnish protection to the steel from surface oxidation, and to give sufficient slag to assure the furnace pulling a steady load, a bare bath being conducive to heavy surging of the power input. As soon as possible a metal test should be taken, and tested by any of the standard methods for its carbon content. It is not necessary for a chemist to make this preliminary unless desired, as it is so easy for the melter to tell by fracture whether his steel is under 0.10 per cent or not.

If the test shows higher than this, ore should be added and the bath boiled until the desired conditions are obtained. If the charge was composed of ordinary grades of soft steel scrap it should always melt down under this figure, unless there has been some electrode trouble, or miscalculation in the selection of scrap.

At this period of the heat a condition similar to a heat of carbon steel is found. The metal is heavily oxidized having an approximate analysis of carbon, 0.05 per cent; silicon, 0.01 per cent; manganese, 0.04 per cent. The slag is thin and black, being heavily charged with the oxides of both iron and manganese.

The second slag now is added consisting of approximately 2 per cent of the charge, burned lime, and about 20 per cent of the lime, gravel or crushed fluorspar. After being allowed a few minutes under the arc to heat, this slag is well rabbled to thoroughly mix up the old slag with this fresh addition. It then is given a heavy dusting of ground coke and the furnace sealed as closely as is possible.

The slag now will be either a black, or a dark brown,



due to the large percentage of oxides contained, but soon will turn to a lighter color. As soon as the metal becomes hot enough so that it will not chill upon the addition of the ferromanganese, this alloy may be added. The usual method is to add approximately 100 pounds at a time placing the alloy on the sill just inside the door, and allowing to remain there for at least two minutes before shoving it into the bath. This is repeated alternately

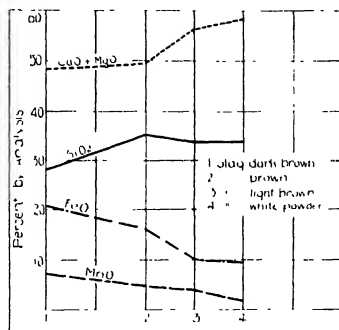


Fig. 34—Course of Slag Changes in Melting Manganese Steel

from both doors until the entire addition has been made. During this time the metal has been heating and after the final addition only a few minutes are required for the steel to reach tapping temperature.

As soon as this heavy charge of manganese is added, the slag will turn quickly to either a deep blue, or a green, depending upon the amount of manganese which enters the slag. Any oxides present in the steel will be eliminated quickly and as reduction proceeds and the metal heats up this manganese in the slag, together with the oxides of iron, will be reduced, their metallic constituents

passing back into the steel. The course of such a slag is shown in Fig. 34.

### *Different Method of Treatment*

To this point the description of the manufacture of manganese steel has paralleled that of plain carbon heat. From here this metal differs in its treatment. In ordinary steel heats, a carbide slag is formed at this time, and the metal is deoxidized by its strong reducing action. However, with manganese steel, due to the large percentage of manganese contained, it is difficult to obtain a carbide slag, although in certain instances the slag will powder on exposure to the air. While the content of manganese and iron oxides in the final slags from carbon steel are extremely low, in making manganese steel it is unusual for these constituents to be much under 2 to 4 per cent for manganese, and 7 to 10 per cent for the iron. Naturally, if the melter waits for the slag to turn into the carbide condition he is likely never to finish the heat. Often, heats of excellent steel may be poured under slags of a distinct green color, and containing as high as 5 to 7 per cent metallic manganese.

The following shows the analysis of a slag which partly powdered on exposure to the air:

	1:00	2:00	2:10	2:45
	P. M.	P. M.	P. M.	P. M.
	Dark		Light	White
	Brown	Brown	Brown	Powder
Silica, per cent .....	28.02	34.70	33.50	33.60
Iron oxide and aluminum oxide.,	20.70	16.00	10.00	9.40
Lime and magnesia .....	48.38	49.49	56.45	58.42
Manganese oxide .....	7.02	4.45	3.75	1.59

Some slag losses on other heats are as follows, the slags being of green of various shades, ranging from a light pea green to a dark sea blue in color:

---

Manganese in Steel	Manganese in Slag
Per cent	Per cent
10.53	6.47
11.11	6.67
11.92	2.79
11.65	1.23
11.26	3.91

Slags continuing from 8 to 10 per cent manganese usually will be green or blue in color; those from 6 to 8 per cent, dark brown; 4 to 6 per cent, light brown; and 2 to 4 per cent, a light brown or whitish gray. Of course, exceptions to this rule will be observed but these occurrences have been found on several hundred heats.

As the slag offers little aid in judging the quality of the metal, recourse must be had to another method, that of using the metal itself as the indicator, regardless of the condition of the slag. Only one point will be mentioned in regard to slag manipulation. That is, the slag should be kept as thick and limey as possible during this finishing to conserve as much manganese as possible. A slag tending toward the acid state always holds a much greater percentage of manganese in combination than a slag of strong basic character. Furthermore, reducing conditions proceed better, and the metal heats faster under the thick lime slag, than under one tending toward the glassy state.

In making carbon steel this feature can be handled by taking a test, breaking it, and noting the solidity. If gassy, or wild, the metal is unfinished. If thoroughly solid, the heat can be poured. With the high percentages of manganese in manganese steel such a procedure is out of the question, for with such a quantity of this oxygen destroying element present it would be impossible for the metal to contain blow holes. However, if a test taken here shows solid this is absolutely no indication that the metal is finished, or in any condition to pour. This manganese was added to a steel which was heavily impreg-

nated with oxides. Naturally, the first reaction will be that the manganese will combine with all the free oxides present, and cleanse the steel from these impurities. An additional amount of oxides is present at this time, actually dissolved in the metal, which will not react at first with the manganese. As soon as all the free oxides are removed, the steel will show solid, but if it were poured containing this amount of dissolved oxides, the result

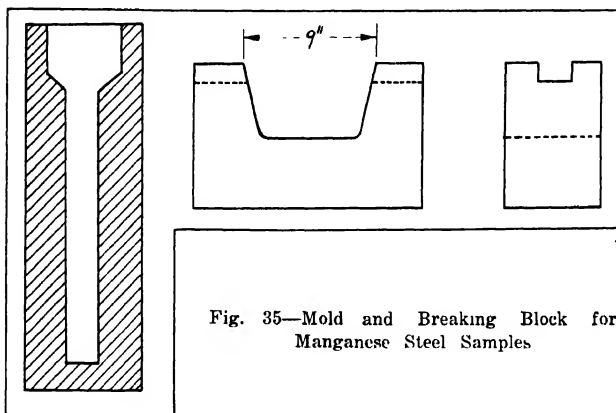


Fig. 35—Mold and Breaking Block for Manganese Steel Samples

would be a heat giving a large proportion of cracked castings, due to the influence of these impurities during the period of solidification.

Therefore, the point of importance is how to tell when these oxides have been removed from the metal. As the steel heats up it becomes more fluid, and is naturally under heavy reducing conditions. These points allow the manganese gradually to absorb all of this dissolved oxide, and free the metal. This generally occurs by the following steps:

1. Heat of carbon steel containing a large proportion of oxides.
2. Manganese of approximately 13 per cent added.
3. All free oxides combine with the manganese as MnO, and pass into the slag.
4. Heavy reducing conditions in slag break up this oxide allowing the manganese to be freed and pass back into the metal.
5. Metal solid at this point. Slag green.
6. Metal heating and slag reducing.
7. As soon as slag begins to get low in manganese, this element becomes active in the metal and gradually exerts a sufficient influence on the dissolved oxides to free them from their combination with the iron.
8. These dissolved oxides gradually are freed from the metal leaving it in a finished condition.

To follow these actions, a special test piece is poured at intervals during the finishing. This is a piece approximately 12 inches long, and  $\frac{1}{2}$  by  $\frac{3}{4}$  inches, poured on end in a sand mold made by pasting two cores together. As soon as solid, this bar is water quenched, and bent until broken. The mold and breaking block are shown in Fig. 35.

The first test taken after all of the manganese is added probably will bend only 90 degrees before breaking, the fracture having more or less of a granular appearance, and in the majority of instances will show colored streaks, indicating an oxidized state. However, as reduction proceeds, this test will begin to show a larger degree of bend, and the fracture will assume a silky appearance, being a silvery white, and absolutely free from any trace of color. When this point is reached the metal is satisfactory and may be poured.

Manganese steel as often described, consists of an iron alloyed with manganese, carbon, silicon, phosphorus and sulphur. The amount of this last named element of course is negligible, for its removal is almost absolute

in the presence of such a large amount of manganese. The manganese sulphide formed rises to the surface where it burns off rapidly as sulphur dioxide.

The amounts of manganese mentioned vary from 10 to 13 per cent, and as might well be imagined, this wide variation offers distinct changes in its properties. Also, it often has been stated that a manganese steel must be as low in carbon as possible, that its ductility may remain high. Figures given have stated that the ratio number should remain as high above 10.00 as can be had, this figure being obtained by dividing the percentage of manganese in the steel by that of the carbon.

The following figures illustrate this point:

Series 1 Percentage		Series 2 Percentage		Series 3 Percentage	
C	Mn	C	Mn	C	Mn
1.01	11.26	1.07	11.75	1.22	12.01
1.00	11.06	1.11	11.92	1.18	12.30
.95	10.86	1.00	11.39	1.15	12.42
.90	10.53	1.05	11.54	1.17	12.84
.93	11.11	.97	11.92	1.16	12.62
.99	10.82	1.04	11.44	1.32	13.07
		1.12	11.63	1.35	13.93
				1.24	12.77

The averages are:

Series No. 1: Carbon, 0.96 per cent; manganese, 10.94 per cent; giving a ratio of 11.40.

Series No. 2: Carbon, 1.05 per cent, manganese, 11.61 per cent; giving a ratio of 11.00.

Series No. 3: Carbon, 1.22 per cent, manganese, 12.74 per cent; giving a ratio of 10.40.

All of these three groups fall within the allowable analysis. All have a higher ratio than 10.00, yet there are great differences in their physical properties.

All of the steels in series No. 3, bent cold on the standard test bar bend 180 degrees without any appearance of a crack on the bent area. The steels in series No. 2 only bent about 120 degrees before beginning to show incipient cracks; while series No. 1 gave only the same results at about 90 degrees. As this bend test is a stand-

ard comparison of ductility, it is easy to see where the above mentioned specifications could be met, and at the same time be filled with a steel of lower quality than desired.

The author has followed this point carefully on several hundred heats and always has found the following points to hold true:

A manganese steel containing under 11.00 per cent manganese always will fail on the bend test at some point between 90 and 120 degrees, regardless of the percentage of carbon, or the carbon-manganese ratio.

A manganese steel containing from 11.00 to 12.00 per cent manganese always will fail at some point between 120 and 180 degrees, regardless of the ratio or the percentage of carbon.

A manganese steel containing from 12.50 to 14.00 per cent manganese always will bend flat on itself, or 180 degrees, without any appearance of cracks, regardless of the carbon content or the ratio. While this gives a large leeway the higher percentage is not essential, a manganese of 12.50 per cent giving equal results with one of 14.00.

Therefore, in specifying manganese steel for parts where extreme ductility and resistance to shock is desired a percentage of manganese between 12.50 and 14.00 per cent should be demanded.

#### *Gives Higher Limit*

Manganese steels between 7.00 and 10.00 per cent manganese will have a higher elastic limit with a greater resistance to flowing under pressure, than the steels of the analysis, mentioned, but at the expense of ductility.

This specification also must include the fact that the carbon manganese ratio must not exceed 10.00. While it is comparatively easy to make steel fulfilling these requirements, it must be remembered that a certain amount of experience is necessary to keep the carbon down and the manganese up. If there were no ratio called for

manganese steel could be made cheaper than at present, but the higher amounts of carbon present would be likely to cause difficulty in cracking during solidification. Often these cracks are interior ones, not apparent to the eye, and only come to light as a failed casting after the steel is placed in service.

The percentage of silicon present in manganese steel runs from 0.30 to 0.80 per cent, and varies greatly due to the percentage reduced from the slag. The ordinary addition before pouring is approximately 0.40 per cent. From the results of many tests it is not evident where silicon plays any part at all in this metal, outside of its final de-oxidizing powers. The writer has seen tests on different steels running from 0.15 to 2.00 per cent silicon give results so close that no difference could be noted.

However, the percentage of silicon should be kept between some such percentages as 0.30 to 0.60 as higher percentages in certain instances might influence the decomposition of the carbides of iron and manganese during the treating process. This is purely speculation anticipated by the action of silicon in the manufacture of *black heart* malleable which manganese steel closely parallels in several points.

#### *Shop Scrap Causes Difficulties*

Making manganese steel with soft steel scrap and ferromanganese is comparatively simple, but when it comes to using up the old shop scrap, difficulties often are encountered. A great deal of experience is required if good steel of regular composition is to be made using shop scrap. Practically, it is impossible to segregate the shop scrap by heats, as this would take up too much valuable space. Consequently, this scrap either must be used as made or allowed to pile up until sufficient quantity is on hand.

From experience it is preferable to allow the heads and gates to pile up until sufficient is on hand to make a



heat containing from 50 to 75 per cent of this alloyed scrap. A heat containing this amount is easier to make than one of 100 per cent, although many fine heats have been made with a complete charge of old material. Using the scrap each heat requires more time and effort, and it is better to use one heat of large proportion than five or six containing smaller amounts. It is no harder to make a good heat from 75 per cent returned scrap than it is from 15 per cent.

The method of operating the furnace on these heats is similar to making the metal from carbon steel scrap with the following exceptions:

The greatest of care must be exercised to prevent any electrode breakage, or any condition which would tend to raise the carbon in undue proportion, for if a high carbon is obtained it is impossible to lower it in the presence of such an amount of manganese.

No reliance can be placed on fracture tests, as regards the percentage of carbon present, for in the presence of over 2 or 3 per cent manganese, a fracture cannot be read with any degree of accuracy. Melters have claimed they could read the carbon on a manganese steel test, but as yet the author has to see one who can back up his boast. Several have failed miserably when actually confronted with the test.

Greater care must be exercised in keeping the slags as heavy in lime as possible, and yet in a fluid condition. This prohibits any additions of sand, and if too thick, fluorspar always must be used for thinning.

Ground coke to reduce the slag must be used with discretion as any careless additions are likely to penetrate to the metal and raise the carbon. Consequently it is seldom that a heat of returned scrap finishes under a white, powdering slag, the finishing slag usually being of a greenish blue.

Consequently more reliance must be placed on the appearance of the metal tests, and their degree of bending.

There seems to be no special manner in which the shop scrap should be charged, tests made giving equal re-

sults regardless of the position in which the scrap was placed. The character of the scrap, regarding its oxidized condition, is important, and the greatest care should be exercised to charge as clean scrap as can be had. Naturally, this follows if the chemical reactions involved in the melting of this steel are considered.

If a heat containing 75 per cent shop scrap is charged, the approximate analysis of the charge in manganese will be from 9 to 10 per cent. It is impossible to lower the carbon greatly by the oxidizing action of rust, the result being that a great amount of the manganese is thrown into the slag. The less oxide present the less manganese in the slag, and the easier it is to clear this slag when reduction starts. Many experiments were conducted to investigate this point, and it always was found that the cleaner the scrap, the better the operating figures, and the higher the quality of the steel. It was found in many cases that it was economical first to place the charge in a rattler and free it of adhering scale before placing in the furnace.

The furnace being charged the current is thrown on, and the heat melted down as for any other class of steel, the only different point being that slightly larger amounts of lime are used at first. This is to supply some medium which will carry the large amount of oxides produced, and tend to prevent them from dissolving in the metal, which would be the case were no such medium present. As soon as the steel is melted, the walls are raked clean, and a test sent to the chemist for analysis of carbon and manganese. The result of his test will determine how heavy an addition of coke can be made for reduction purposes.

As the metal gets hotter, more lime and spar are added, and the slag given a good dusting of coke. More or less of this coke may be added depending on the manganese-carbon ratio. The doors are sealed tightly and reduction commences. Tests should be taken at intervals

to check this action. During this period the slag will change from a dark green, to one of a lighter color, but rarely will show white. When a slag of constant color is obtained, usually a pea green, the remainder of the manganese required, calculated from the previous analysis, correction being taken for future reduction, is added in the form of the ferro, and the finishing of the heat begins. See Appendix Tables 14, 15 and 16 for logs of manganese steel heats.

Metal tests first taken will show a heavy degree of color on fracturing, the colors ranging from violet, blue, green, and to the different shades of red. The first bends usually will be poor. However, as soon as the reduction begins to cleanse the metal, these conditions will change. The tests will give a greater degree of bend, and the fracture gradually will free itself of any color, and will, upon attaining its finished state, have a clear fracture, with the soft texture, and silvery lustre of a water quenched tool steel. Such a metal is in condition to pour.

During the finishing period, the viscosity of the slag will change, due to the large amounts of oxides being removed from combination, and much manipulation is necessary to keep this slag in a free flowing, liquid condition. This will necessitate frequent additions of either lime or spar, together with as much coke as is allowable. When the steel gets to the point where a good finished bend is obtained, another test should be sent to the chemist for his final analysis, and no heat ever should be poured without such a final safeguard. Some tabulations of manganese scrap charges are given in Table XXVI.

#### *Ore as a Deoxidizer*

When ore, or mill scale is used to cut the carbon it is known that the manganese also is oxidized, and goes into the slag as  $MnO$ . Therefore, it was decided to try manganese ore in place of the iron oxide. Theoretically

**Table XXVI**  
**TABULATIONS OF MANGANESE SCRAP CHARGES**

Manganese scrap					
per cent	50 0	70 0	80 0	70 0	50 0
Condition	Rusty	Rusty	Rusty	Rattled	Rattled
How Charged	Center	Top	Top	Center	Center
Current on	8 45 am	9 35 am	3 35 pm	3 35 pm	1 15 pm
Contact (poul)	9 15	10 05	6 05	1 00	1 40
Melted	11 10	1 15	7 35	6 15	3 45
Tapped	12 15	2 20	9 00	8 05	6 15
Total time	13 30	4 45	5 25	4 30	5 00
First charge					
Manganese ore	none	12 00	6 35	4 55	2 45
Scale	10 55	11 05	6 45	6 05	3 45
CaF	11 20	12 50	6 55	5 35	3 55
Lime	9 55	11 05	7 00		3 05
Sand	11 15	1 05	7 25	6 35	4 25
Coke	11 15	12 55	7 35	6 35	4 25
Ferrosilicon		2 05	8 55	7 00	4 35
Total pounds					
Manganese ore	none	60	60	170	150
Scale	60	30	30	95	80
CaF	20	15	25	40	40
Lime	85	145	190	215	250
Sand	15	30	25	25	15
Coke	85	155	85	110	120
Ferrosilicon	30	25	25	50	45
Ferromanganese	630	332	324	395	610
Final slag			Light	Light	Bluish
			Green	Green	Green
Final temp (skin test)	60 sec	40 sec	60 sec	40 sec	45 sec
Manganese per cent					
theoretical	13 43	13 29	14 14	13 22	13 25
Manganese per cent					
actual	13 23	11 86	12 14	12 55	12 50
Carbon per cent	1 30	1 25	1 33	1 29	1 27
Side Walls.					
Before	OK	Thin	Thin	OK	OK
After	OK	Thin	Thin	Cut	Cut
Hearth					
Before	Hole	OK	OK	OK	OK
After	Hole	OK	OK	OK	OK
Metal tapped	6430 lbs	5655 lbs	6010 lbs	6200 lbs	6400 lbs
kw Hrs	2500	2500	2500	3000	3000
Per ton	812	887	883	968	938
Time per ton	1 05 hr	1 10 hr	1 50 hr	1 25 hr	1 35 hr

The following data cover 86 heats of intermittent operations.

Average pour of metal, 6708 pounds, or 3 354 tons

Average charge, 6942 pounds, or 3 471 tons

Melting loss, 234 pounds, 0 117 ton, or 2 55 per cent

Average time of heat, 5 hours, 26 minutes

Kilowatt-hours per ton of steel poured, 1002

Kilowatt-hours per ton poured on first heat of day, 1055

Kilowatt-hours per ton poured on second heat of day, 948

Highest kilowatt-hours per ton of steel poured, 1385, lowest, 700

Average manganese loss from total charge, 2 16 per cent

Average manganese lost from ferromanganese, 1 26 per cent

Average manganese effective from alloy, 98 74 per cent

Average manganese in charge, 11 80 per cent

Average manganese in steel, 11 63 per cent

Average preliminary carbon using no shop scrap, 0 10 per cent

Using small amounts of shop scrap, 0 26 per cent

Average tonnage, 0 18 per cent

Average pickup from 100 pounds manganese, 0 096 per cent

Average manganese-carbon ratio, 10 77.

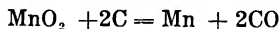
Average heats from roof, 25

Average heats from silica lining, 35

Electrodes per ton of steel poured, 33 8 pounds

These data were collected during the experimental period on remelting manganese steel scrap, and it is natural that the results shown are not as good as have been obtained from later operations. These figures are given mainly to show various differences in the melting practices followed to determine results under changing conditions, and the effects of various additions.

this would cut the carbon, and yet leave a high residual manganese in the steel according to the reaction:



This was tried using a heavy blue black manganese ore, analyzing 50 per cent metallic manganese. The comparison follows:

	Manganese ore	Mill scale
No. of heats . . . . .	13	13
Av. wt. shop scrap . . . . .	1421	1290
Av. wt. total charge . . . . .	7225	6827
Av. wt. total pour . . . . .	7028	6661
Av. melting loss, per cent . . . . .	2.7%	2.4
Manganese ore added per heat . . . . .	36	.....
Av. mang. in total charge . . . . .	12.68%	12.53%
Av. manganese in steel . . . . .	11.61%	12.11%
Av. carbon in steel . . . . .	1.03%	1.09%
Av. manganese-carbon ratio . . . . .	11.29%	11.10%
Av. preliminary carbon . . . . .	0.27%	0.19%
Av. carbon in charge . . . . .	0.38%	0.37%
Av. carbon oxidized from steel . . . . .	0.11%	0.18%
Av. kwh. per heat . . . . .	3154	3384
Av. kwh. per ton of charge . . . . .	876	936

Some comparative results using ore and scale are given in table XXVII.

From these experiments it was found that the manganese losses were greater with the ore. The preliminary and final carbons were higher, due to the fact that not as much carbon was oxidized. It required less power when using manganese. The manganese-carbon ratio was better with the ore, giving a final steel lower in carbon in proportion, even though higher at first. When the scrap was rattled, and free from rust, the results with ore were excellent.

This practice of cleaning the scrap and using manganese ore has not been adopted as standard practice. When used in this manner the ore is highly efficient.

#### *Reducing Manganese from the Slag*

From time to time, various methods are advocated to reduce manganese from the slag back into the bath. Practically all of these methods have been tried by the author

in an attempt to obtain white slags on heats containing manganese steel scrap, but all have proved unsuccessful. Such materials as aluminum, silicon, magnesium, etc., added to slags only raise the costs without any beneficial

Table XXVII  
COMPARATIVE RESULTS WITH ORE AND SCALE  
RESULTS FROM ORE HEATS

Mn	Ore			
C	efficiency	Bend on	Mn in steel	C in steel
Ratio	per cent	test bar	per cent	per cent
10 30	97 4	Very good	13 88	1 35
11.20	73 5	Very good	11 72	1 05
11 30	90 5	Fair	11 72	1 14
10 50	91 0	No good	11 09	.96
11 20	86 5	No good	10 76	.90
10.85	64 5	No good	9 76	.90
10.70	79 0	Good	11 24	1 05
11 65	101 0	Excellent	12 58	1 08
11.83	100 0	Excellent	12 08	1 02
11 85	90 0	Excellent	12 68	1 05
11 85	91 5	Excellent	11 97	1 01
10 15	96 5	Excellent	12 25	1 21
11.12	88 45		12 00	1 08

## RESULTS FROM SCALE HEATS

Mn				
C		Bend on	Mn in steel	C in steel
Ratio		test bar	per cent	per cent
8 25		No good	7 98	.97
10 30		Good	10 99	1 07
11 40		Good	11 89	1 04
12 00		Fair	10 89	.91
11.10		Excellent	12 18	1 10
10 40		Excellent	11 94	1 15
11 05		Excellent	12 15	1 10
10 30		No good	10 66	1 03
12 10		Excellent	12 52	1 02
12 30		Excellent	12 58	1.04
12.30		Good	11 92	.97
10 50		Excellent	11 62	1 11
11.10			11 65	1 05

results. Only some carbonaceous material successfully will clear a slag from a manganese steel heat. Charcoal is too light and rides so high on the bath that its efficiency is low. Coal contains too much ash. The only material

remaining is coke, and this should be as high grade as it is possible to obtain. Under no circumstances should coke sweepings be used in making manganese steel. Table XXVIII gives a comparison of recarburizers.

As mentioned earlier in this chapter, the influence of silicon on manganese is small. While this is true of steel made from a carbon steel base, with ferromanganese added, certain exceptions arise when remelting alloyed scrap. This was noticed first by the author several years

Table XXVIII  
COMPARISON OF RECARBURIZERS

	High grade coke	Low grade coke	Gas carbon pea size
Charges: Shop scrap. . . . .	884	884	1005
Punchings . . . . .	4760	4354	4379
Turnings . . . . .	840	523	553
Ferromanganese . . . . .	1020	926	923
Total . . . . .	6620	6687	6860
Total poured . . . . .	6351	6501	6673
Loss in pounds . . . . .	269	186	187
Loss in per cent . . . . .	3.5	2.6	2.6
Melting efficiency . . . . .	96.5	97.4	97.4
Time of melting, per ton . . . . .	1:13	1:14	1:135
Time of charging, per ton . . . . .	5.7	6.9	4.8
Kwh. per ton of charge . . . . .	925	830	850
STEEL:			
Preliminary carbon . . . . .	0.08	0.13	0.21
Final carbon . . . . .	1.16	1.02	1.06
Silicon . . . . .	.47	.53	.30
Manganese . . . . .	12.13	11.88	12.12
Manganese in total charge . . . . .	13.10	13.40	13.50
Loss in points (0.01 per cent) . . . . .	87	152	138
Loss in percentage of charge . . . . .	6.65	11.35	10.20
Efficiency of ferromanganese . . . . .	97.05	91.75	92.15
Manganese-carbon ratio . . . . .	10.55	11.60	11.45

ago when in charge of the metallurgical work for one of the prominent manganese steel casting companies.

This phenomenon first was encountered when samples were being drilled for analysis by the chemist. He reported difficulty in obtaining samples by the usual method, that of using a special, high-speed drill, operated

at slow speed with heavy pressure. On investigating, interesting facts were discovered.

Manganese steel, as ordinarily made, can be drilled easily by this special tool. It was found that the steel would suddenly get harder by progressive steps, over the course of several heats, until the climax was reached, when it would get soft again gradually. Steels at the one point could be drilled only with the greatest difficulty.

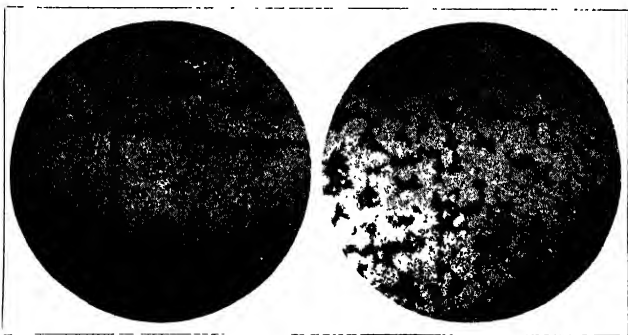


Fig. 36—Bar as Cast and After Heat Treatment  
Poured from Metal Analyzing Mn 12.50 Per Cent, C, 1.07 Per Cent.  
Carbon was 0.24 Per Cent When First Melted Down. Bar Bent  
180 Degrees on Itself Without Checking

This hardness was found to be accidental, as it occurred only periodically. This rise and the subsequent fall lasted for two to three heats each way. An examination of the test bars showed patches of an iridescent color on the surface near the head, with all the colors of the spectrum, and having the appearance of a variegated rainbow. Other specimens would show spots of a silvery, whitish color. Soft steel bars would exhibit none of these properties.

Untreated bars when broken showed all classes of structure from a fine, soft, silky grain, up to the coarsely



crystalline structure showing the familiar right angle appearance due to the effect of chilling on the manganese.

Test bars from these heats bent 180 degrees without any trace of cracking, but seemed to require a harder blow than usual. The main characteristics of this steel were great hardness, and a higher degree of stiffness. Test samples were polished and photomicrographs taken. Two sets of these, with their attendant data are shown

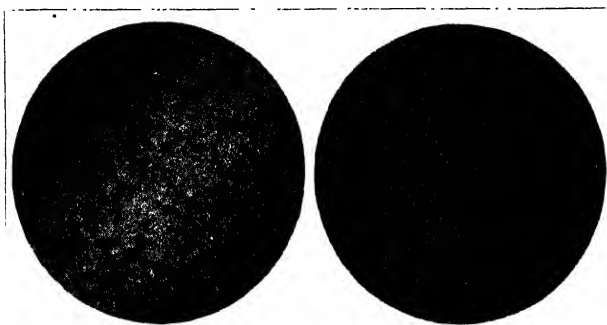


Fig. 37—Bar as Cast at Left and After Annealing at Right  
Poured from Metal Containing Mn, 12.39 Per Cent, C, 1.02 Per  
Cent. Carbon was 0.18 Per Cent When First Melted Down.  
Bar Bent 180 Degrees on Itself Without Checking

in Figs. 36 and 37. They show no unusual structure compared with ordinary steel samples examined.

It was discovered that these hard tests always occurred on heats where shop scrap was remelted, and on the heats which were heated to high temperatures during reduction. Analysis showed silicons approximately 0.20 per cent higher than usual. While there was never any definite solution of this phenomenon it has always been the author's opinion that this hardness was caused by some peculiar condition caused as a combination of

this extra silicon reduction in the presence of unusually high temperatures.

Carbon steel of approximately the same analysis, and cast under the same conditions, generally will have the same structural appearance when a bar is fractured. This does not hold for manganese steel, the fractures cast under similar circumstances having a wide range of appearance. Some of these fractures are shown in Fig. 38,

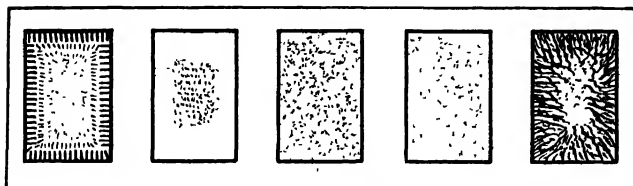


Fig. 38—Typical Fractures of Manganese Steel Bars

the sketches being taken from standard bend test bars immediately after being broken under a steam hammer. All were cast in the same manner, being gated at the top, four bars being cast at one pour. The difference probably is due to varying temperatures at the time of pouring.

While the main activity of the metallurgist in a shop making carbon steel castings is keeping the quality of the steel up to par, his main point of interest is in following the melting practice, together with miscellaneous testing, etc. However, in the manganese steel shop the actual making of the metal is one of the least of his worries. His trouble arises from heats of seemingly proper analysis, which crack during treating, or in the sand, which will not give a satisfactory bend test, or which exhibit some other peculiar phenomena.

Manganese steel, as it comes from the sand, is as brittle as the hardest white iron. Naturally, in this con-

dition it will crack or check on the least provocation, and the greatest care must be exercised by all concerned until the castings have gone through the heat treating process.

### *Annealing Manganese Steel*

After the castings have been cleaned they are loaded on brick topped cars, the top of the car forming the bottom of the annealing furnace. The usual practice is to have a load of castings of approximately uniform size and shape, that a more uniform heating of the entire batch may be obtained. As manganese steel cannot be finished by tools, grinding wheels are used exclusively, and the greatest of care must be exercised during the annealing operation. If the metal is heated too quickly, there is a chance of these brittle castings cracking. If heated too slowly, the oxidation or scaling will be excessive, often allowing insufficient stock for finishing. If the heat is irregular in different parts of the furnace, some of the castings will warp, with attendant trouble when checking to final size and shape.

Formerly heat treating was performed either in oil or gas fired ovens of a special shape, so arranged that the flames used were soft and luminous, and so baffled that there was no chance of a direct impingement on the castings. This has been superseded in many shops by the electric treating furnace, which, has many advantages.

The furnace is heated slowly, in as much of a neutral atmosphere as possible, until a dark red predominates, when the heating may be increased to approximately 1800 degrees Fahr., when the furnace is so controlled that it is held at this point until the castings have absorbed this heat equally. The temperature then is raised to 1850 degrees, and the castings allowed to soak until the heat has been distributed uniformly through their mass, the time

depending on the shape of the casting, and the thickness of section.

As soon as the heat has penetrated throughout, the car of castings is withdrawn from the furnace, and the castings dumped into water as cold as it is possible to obtain. This operation requires speed, for the difference of a few seconds may result in improper quenching, especially on thin section work. Usually, the water is kept circulating. The quicker the castings enter the quench the better their quality. For this reason the cars often are arranged so that as they are withdrawn from the furnace, the body is raised, dumping the charge automatically into the quenching tank. This operation takes approximately five to ten seconds.

After cooling, the castings are taken from the quenching tank. They now are toughened ready for final finishing and use. All finishing is done with grinding wheels.

On certain classes of work, inserts of cast iron or soft steel are used, being cast when the piece is poured. These find wide use for certain classes of work, especially hubs on sheaves or wheels, where the wear is light, and this lower strength metal is suitable.

Manganese steel exhibits the same properties as cast iron when poured into chill molds, but instead of becoming brittle it is strengthened. A test bar from  $\frac{1}{4}$  to  $\frac{1}{2}$  inch thick, when poured in a chill mold will give a bend similar to a bar treated and quenched. A similar specimen cast in sand probably will bend from 45 to 90 degrees, while a section of 3 inches poured in sand will be glass hard. However, after treatment, all three tests will show similar properties when bent. A great difference in structure may be obtained from different sand cast fractures, but after treatment all will have the soft, silky fracture, with great strength and toughness.

Difficulty in obtaining a uniform heat and quench,

limits the thickness of section which may be made of this metal. At the present time this maximum thickness is about 5 to 5½ inches. Heavier sections either are cored, or a carbon steel insert is placed in the center of the section, to act more or less as a solid core. This aids in relieving the great strains which would be caused by such a harsh quench as cold water when acting on a section of greater thickness. Manganese steel has such superior strength and toughness compared with ordinary metals, that sections of the maximum mentioned prove suitable for any class of work. This in itself is an important characteristic as it means great saving in weight of metal to fill a desired specification.

In the cast state, manganese steel is composed of austenite and free cementite. It is this proportion of cementite which gives it the brittleness associated with its cast condition. This proportion of cementite will either be smaller or larger, according to the proportion of chill during casting, the bend depending directly on this ratio. A piece chilled quickly will give a large degree of bend, on account of its low proportion of cementite, and *vice versa*. However, austenite, as is well known, confers a high degree of toughness and resistance to wear to steels containing it in quantity, and the treatment of manganese steel is intended to change the structure of the metal to the condition where its entire structure is austenite.

In steels containing from 12 to 13 per cent manganese, the structure at temperatures higher than 1800 degrees, will be composed entirely of austenite. If the metal is allowed to cool slowly, this structure changes, due to this slow transition, and considerable cementite is formed. If the steel is heated again the structure will pass over into austenite at about 1800 degrees. The problem is to hold the carbides in solution as austenite, and the solution is to quench as rapidly as possible from temperatures

above this critical point. If the steel is heated again past 700 degrees this austenitic structure will be destroyed.

This latter proves valuable in the recovery of manganese steel scrap, as the pieces, if of large dimension, have only to be heated to a good red, and allowed to cool slowly

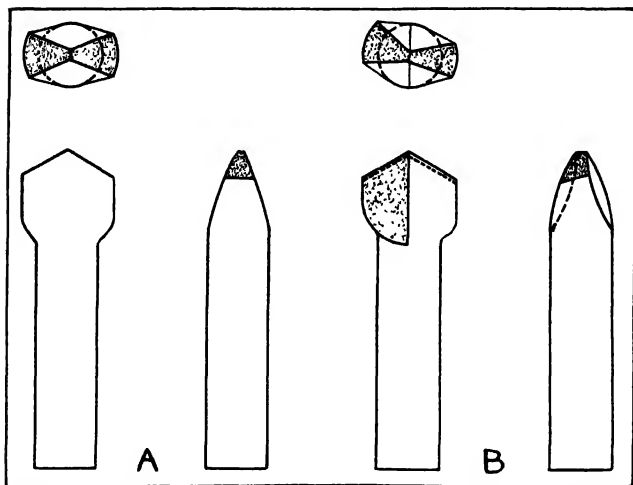


Fig. 39—Progressive Steps in Forging a Special Drill for Taking Manganese Steel Test Samples

in the furnace, when they can be broken as easily as cast iron, by a drop ball.

This steel has a greater shrinkage than ordinary carbons, the average being about  $\frac{5}{16}$  inch to the foot. Naturally, this adds to the molders difficulties, requiring larger shrink heads, and more care in placing gates and risers that there may be no binding during solidification, causing cracks and tears. This feature, coupled with the brittleness, requires a careful check on the design of the

pattern, and results in many differences over ordinary steel practice.

It has been found through experience, that the point of greatest trouble is cracking of the castings, either immediately after pouring, or during the treating operation. The great majority of these failures have started from a sharp corner on the casting. Consequently all castings, as far as possible, are made with rounded corners. All right angled sections are filleted heavily, and brackets and *dogs* are used freely. All holes are cored, being made as small as about 1 inch. When smaller holes are required soft steel inserts are used.

Manganese steel, due to its high percentage of manganese, attacks ladle linings, causing considerable slag to form during the pouring of a heat. This must be watched carefully and skimmed or it will cause considerable trouble with defectives. On this account, tea-spout ladles find use in the majority of shops.

Due to the necessity of pouring the steel extremely hot, the sand required for molding must be highly refractory or cleaning costs will mount. This necessitates a sand of the highest quality, and cuts down the amount of old sand which may be used in a mix. Molding sand used on manganese steel generally will analyze higher than 92 per cent silica, with low percentages of iron and lime.

### *Testing Manganese Steel*

As this metal cannot be touched by an ordinary drill, special methods must be employed to obtain drillings for chemical analysis. These are obtained by the use of a special shaped drill as shown in Fig. 39. A piece of high speed steel about 4 inches long, and  $\frac{5}{16}$  inch in diameter is heated up to a yellow and rapidly forged to the shape shown in *A*. This is then heated up to a white heat, and quickly quenched in kerosene, after which it is ground to the shape shown in *B*. This tool is used in a drill press

having a slow speed, and allowing a heavy pressure to be used. Drillings can be made rapidly in this manner, usually coming off as pure white splinters, although there are times when the tool will bring off shavings several inches long. The author has drilled through a manganese steel plate 1 inch thick with such a tool. For the first half inch the tool went easily, but from there on great difficulty was had, the tool requiring constant re-

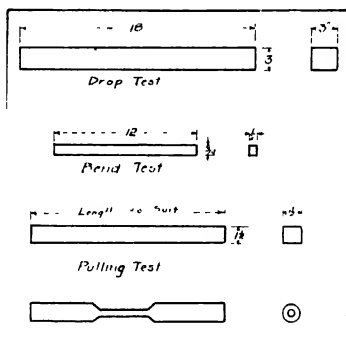


Fig. 40--Typical Bars for Drop, Bend and Pulling Tests

sharpening. The last  $\frac{1}{8}$  inch was impossible to cut clean, the tool actually tearing its way through by pressure from the press.

The drillings are analyzed by the ordinary methods for manganese, carbon, silicon, phosphorus, and sulphur.

Three different bars, as shown in Fig. 40, are used for testing the physical properties. These are subjected to the drop test, the pulling test, or the bend test. The drop test is seldom used outside of rail work, but is made by placing the bar on two rigid supports, and dropping a hammer of known weight a specified distance, and noting the number of blows the bar will stand before rupture.



As this bar is 3 inches thick the test is only useful on heavy sectioned work.

The pulling bar is standard size, and is tested for tensile strength, elongation, etc., in exactly the same manner as carbon steel.

Of all the tests, both chemicals, and physical, the bend

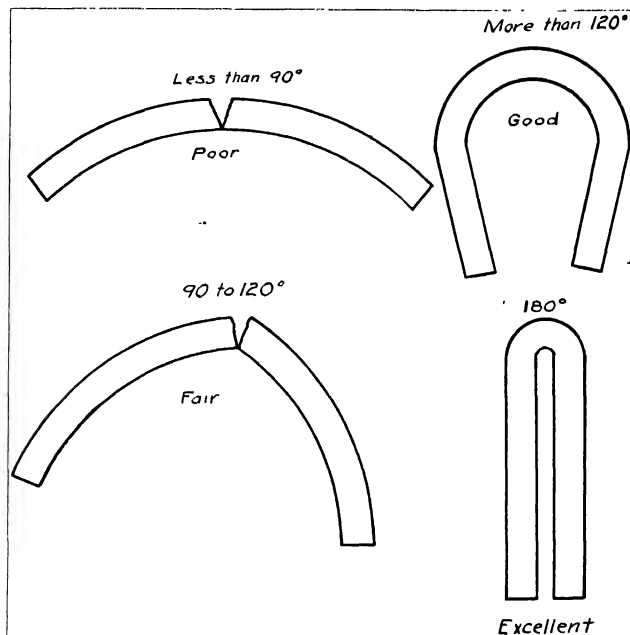


Fig. 41—Bend Tests Afford a Comparison of Manganese Steel Quality

test is by far the most important, and furnishes a better estimate of the quality of the steel than any other method. These bars are cast usually four to six in a flask, one set being made on each heat. One of these bars is drilled

and the drillings used for chemical analysis. Two are sent to the testing department at once, heated in a small electric furnace to 1850 degrees Fahr., water quenched and bent. This bending serves as a check on the metal making department and is classified as shown in Fig. 41 as either excellent, good, fair or poor.

The remaining bars are treated in the annealing furnace with the castings from the same heat, and their bend is checked against those treated under perfect laboratory conditions. Any great difference shows poor annealing, and the annealing process must be repeated.

Formerly, when manganese steel was made in the converter, a bend of 120 degrees was considered excellent, but the electric furnace has increased the metal in quality to the point where a bend of 180 degrees is called for.

Manganese steel, although tough, and with great resistance to abrasion and shock, has one disadvantage. It tends to spread or peen under pressure. The metal itself is soft, and with its great elongation rapidly flattens out under repeated pressure. This is due to its low elastic limit in proportion to other classes of steel.

This characteristic has been noted in ball mill liners, where the terrific peening action of the ore and ball charge often has welded together the manganese steel liners requiring the cutting torch to tear loose when repairing of the mill was necessary.

### *Special Manganese Steels*

Manganese steels for special service are of varying carbon content, with the manganese percentage running from 1.25 to 1.75 per cent. These classes of castings have been known for many years, and offer such excellent properties that they may be classed among the true alloy mixtures. This metal offers great strength with a maximum of ductility, besides being naturally solid. Under most

treatments, it offers free cutting qualities, giving a beautiful appearance when machined, and being capable of taking a high polish. Therefore it finds great use for any class of casting requiring a metal of high test, which must have considerable machining performed on it before ready to use. For castings to resist high pressures it cannot be excelled, seldom requiring bushing to hold liquids under heavy pressures.

These special manganese steels should be differentiated from the high manganese metal which has been described. The high manganese steels range from 7.00 to 14.00 per cent in manganese content. The use of the previously described material is confined to service where extreme hardness is essential, such as in railway crossings and frogs, crushing or grinding machinery and in heavy duty pumps, gears and other parts. It is not machinable, but may be ground to finish surface. The high manganese steel ranges from 90,000 to over 100,000 pounds tensile strength, with an elastic limit of about half those amounts and elongation of about 20 per cent.

The special manganese steel at present under consideration has a much lower percentage of manganese. Its manufacture offers no difficulties and it may be made either in the acid or basic furnace. Good scrap should be used as a base, and the manganese added sufficiently ahead of the pour to assure perfect diffusion.

This percentage of manganese makes this steel sensitive to treatment, and considerable care must be exercised in this respect. While it does not appear possible that such a metal could contain oxides, such is the case, and the furnace practice must be of the highest if good results are to be obtained. The oxide manifests itself in cracks or tears, generally appearing during or after heat treatment. Another prolific cause of rejections are non-metallic inclusions, such as slag or sand, causing cracks to appear, often being internal and not appearing until

the steel is in service. Consequently, the molding practice must be watched carefully, and all steel should be

**Table XXIX**  
**COMPARATIVE TEST OF MANGANESE STEEL**

<b>Water Quenched</b>				
Treatment Degrees Fahr.	Drawn	Tensile strength pounds per square inch		Bend test degrees
1700	1300	103,200	4.7	.
	1100	106,700	3.0	..
	900	121,000	2.7	...
1600	1300	97,500	10.2	90
	1100	102,000	8.0	30
	900	115,000	7.5	30
1550	1300	94,000	12.1	120
	1100	98,500	6.3	40
	900	107,400	6.1	30
1500	1300	93,000	11.1	120
	1100	96,300	7.9	60
	900	98,900	6.8	60
1450	1300	98,000	12.0	100
	1100	102,100	9.1	75
	900	109,600	5.3	30
1400	1300	86,000	7.2	45
	1100	89,300	5.1	.
	900	91,100	4.0	.
1300	1300	88,100	8.3	.
	1100	90,500	8.0	.
	900	93,200	7.7	.
<b>Oil Quenched</b>				
Treatment Degrees Fahr.	Drawn	Tensile strength pounds per square inch		Bend test degrees
1700	1300	101,100	8.5	60
	1100	103,650	8.1	50
	900	109,300	6.8	30
1600	1300	90,000	19.7	180
	1100	93,500	18.9	180
	900	100,250	16.3	120
1500	1300	94,400	21.2	180
	1100	94,900	20.0	180
	900	99,750	17.5	150
1450	1300	92,200	21.1	180
	1100	91,700	20.2	180
	900	96,400	18.7	160
1400	1300	84,000	13.3	90
	1100	86,500	12.7	90
	900	83,750	9.5	60
1700	1300	92,000	9.5	90
	1100	94,400	9.3	30
	900	97,350	8.9	60
1600	1300	91,750	22.5	180
	1100	94,000	21.7	180
	900	96,250	20.3	180
1500	1300	89,600	24.0	180
	1100	91,500	22.7	180
	900	92,000	19.6	180
1400	1300	82,700	14.1	120
	1100	84,000	12.2	120
	900	84,500	11.9	90

\*All tests made on standard test bars taken from heavy sectioned work. Thinner section would naturally show greater differences.

allowed to stand in the ladle at least ten minutes before pouring the first mold, bottom pour ladles being strongly recommended.

This steel does not exhibit any of its beneficial properties unless given a heat treatment. Small size castings may be water quenched with safety, large size work showing superior results when given an air quenching followed by a draw to the proper ductility.

Some interesting figures obtained on special manganese steel made in an acid electric furnace reflect the results obtainable by proper heat treating. An average of a number of tests made on steel of 0.25 to 0.30 per cent carbon, with manganese at 1.25 to 1.30 per cent showed tensile strength totals ranging from 82,000 to 92,000 pounds per square inch. Standard bend bars were used. When annealed and cooled slowly in the furnace from 1700 degrees, Fahr., the tensile strength was 92,000 pounds with an elongation of 11 per cent and a cold bend of 120 degrees. The same treatment from a maximum of 1600 degrees gave a lower tensile but with 17.5 per cent elongation and 130 degrees bend, while when the initial temperature was dropped to 1500 degrees, Fahr. the maximum elongation of 18.5 per cent with a bend of 130 degrees was attained. Below this temperature the tensile and other properties were decreased.

Table XXIX gives results obtained on manganese steel of the analysis described in a series of tests, using either water or oil for quenching.

Manganese has a tendency to lower the critical temperatures of steel approximately 5 degrees Fahr. for each 0.10 per cent manganese. With a steel approximating 1.50 per cent manganese this would amount to 75 degrees Fahr. However, it may be seen from the tests shown in Table XXIX that on heavy sectioned work it may be treated safely as for a plain steel of equal carbon content. This steel is not particularly sensitive to small

differences in the temperatures of either heating quenching, or drawing, which makes its use attractive to the shop operating under a heavy production schedule as these castings may be treated coincident with plain carbon pieces.

The accompanying tests, summarized in Table XXX, were reported by John Howe Hall in a paper before the American Institute of Mining and Metallurgical Engineers, cover a series of results on this steel as made in

Table XXX

## PHYSICAL PROPERTIES OF MANGANESE STEEL

Carbon per cent	Silicon per cent	Manganese per cent	Tensile strength pounds per square inch	Elastic limit pounds per square inch	Elongation per cent	Reduction of area per cent
0.26	0.38	1.33	80,000	51,500	20.8	31.8
0.26	0.38	1.33	109,000	70,000	21.2	28.9
0.36	0.33	1.33	85,750	46,100	24.0	35.7
0.27	0.28	1.38	96,000	59,000	23.9	31.5
0.35	0.33	1.38	94,030	46,790	24.5	35.1
0.35	0.33	1.38	106,160	78,960	17.7	34.0
0.26	0.38	1.39	73,500	48,500	28.9	43.4
0.34	0.33	1.39	75,500	42,000	29.2	50.6
0.47	0.39	1.40	106,160	61,380	20.9	36.9
0.34	0.51	1.41	78,000	53,000	26.0	34.7
0.38	0.24	1.72	100,500	50,000	19.8	34.7
0.34	0.26	1.79	84,250	46,500	27.2	52.5
0.27	0.30	1.91	91,400	54,250	23.7	31.2
0.32	0.19	2.38	103,400	59,390	18.2	29.2

the basic electric furnace. All specimens were given the following treatment:

Air quenched from 90 degrees Cent., drawn back to 700 degrees Cent. and allowed to cool in the air.

Mr. Hall in the *Iron Age* of September 28, 1922 offers the results of a series of tests covering these high manganese steels in combination with nickel, the latter varying from 1.15 to 1.80 per cent. As would be expected these steels show the great ductility of the manganese combined with the high tensile strength and elastic limit of the nickel, producing a metal of unusual quality. In these tests the carbon content ranges from 0.27 to 0.38 per cent; the sulphur from 0.032 to 0.040 per cent; phosphorus from 0.035 to 0.045 per cent, and the silicon from 0.30

to 0.40 per cent. Copper from 0.40 to 0.80 per cent also is contained in the analyses listed. The results of these tests are summarized in Table XXXI on page 224.

From the data given it may be seen what a great variety of alloys in their different combinations may be used, and what high test results may be had from their use. In the manufacture of alloy castings it is by far the best and safest method to use the steel requiring the simplest melting and treating procedure with the necessary qualifications amply to cover the specifications.

# XI

## NICKEL STEEL

OF LATE years a considerable increase in the amounts of alloy castings made has been noted throughout the country. This has been caused, in part, by the gradual tightening of specifications, especially for castings used in the automotive industry. As it became more difficult for manufacturers to supply the demands of their customers from the ordinary grades of plain steel castings different alloys were developed. At first, results were not good, due to the lack of metallurgical knowledge in these lines. However, as time passed,

Table XXXI  
PROPERTIES OF MANGANESE-NICKEL STEEL

Manganese per cent	Nickel per cent	Tensile		Elastic limit pounds	Reduction		Bend degrees
		strength pounds per square inch			per cent	Area per cent	
0.81	1.60	92,283		55,767	22	37	120
0.93	1.44	92,334		55,003	21	31	120
1.02	1.15	88,616		54,494	25	40	120
1.04	1.14	92,691		56,277	22	34	120
1.11	1.34	95,543		59,078	22	37	120
0.93	1.12	90,042		57,550	23	37	120
1.18	1.60	92,691		55,003	22	36	120
1.15	1.58	94,830		54,748	22	37	120
1.03	1.73	96,052		59,087	25	41	120
1.21	1.24	91,366		55,003	25	44	120
1.15	1.54	81,343		60,096	25	41	120
1.15	1.80	92,181		55,288	23	36	120

more data were obtained through countless experiments, and the different steps in manufacture of alloy castings were so standardized that their commercial production became possible.

As soon as the worth of alloyed steel castings became apparent, considerable research was made to substitute these products for forgings. The results have been so satisfactory that each year shows a great advance in alloy castings' use. Where a superior product with unusual qualities is desired, forgings often are of



such a shape that the cost becomes excessive. Further, in many instances forging is impossible, due to the complicated design. In these cases alloy castings may be used to advantage.

That alloy castings of suitable strength have an important place in industry is proved. Some of their greatest advantages are as follows:

Castings of complicated shape can be made of equal strength, and at considerable less cost than forgings.

Casting can be used for purposes where a forging is unsuited.

With their greater physical strengths and ductility, alloy steel castings of a much lighter section can be used than forgings or some other classes of castings. This is extremely important in classes of work requiring a specified strength at a minimum weight, as for instance in automobiles, tractors, locomotives, and for reciprocating parts of machinery in general.

The same analysis of metal may be used for widely differing purposes, merely by changing the heat treatment. This is extremely important when the value of the casting as scrap is considered. For instance, the bucket pin of a dredge line—when made of manganese steel as formerly was the practice, the piece would wear enough on one side to cause it to be scrapped, the un-machineable properties of the steel causing the total value of the casting to be only that of scrap. On the other hand when a pin made of alloy steel becomes useless in the bucket line, it may be removed, annealed, and used for some other purpose. When it is considered that these dredgers are used many miles from a repair base these usable steels are of the utmost importance for quick replacement when a breakdown occurs. Alloy steels may be used for keys, pins, washers, etc. Having a supply of old pins always on hand, the dredger foreman is never at a loss when an unforeseen accident occurs. He merely forges a pin to the size and shape desired, and then treats it either for greatest hardness or maximum toughness.

Castings can be made of any shape, and with any desired characteristic. They may be either glass hard, or

exceedingly tough. Some classes of work can be made glass hard on the face, and tough on the back, as for instance in a crusher jaw.

Naturally, when the steel is made for such strenuous service it must be of the highest quality, and of absolute regularity, if the best results are to be obtained. This has resulted in the use of the basic furnace in the majority of cases, although there are some classes of alloy steels made extensively by the acid process. Whatever process is used, the furnace practice must be of the best from a metallurgical standpoint. Alloy steels require widely different furnace practice from that found standard for the plain carbon analyses.

### *Choosing Scrap*

Some classes of alloy castings are worth over 25 cents per pound, and a few dollars a ton difference in the scrap used is of slight consequence. Therefore, it is best to use a good grade of scrap metal for the raw charges. Scrap having a high percentage of loss during melting is not desirable, due to the percentage of oxide in relation to the area of the charge. Such classes of scrap as borings, turnings, light forge flashings, stampings, etc., fall under this classification. However, these classes of metal may be used if clean, being mixed with heavier scrap. Such classes of charging material as ingot butts, clean punchings, heavy boiler plate, low-phosphorus steel rail, old castings, etc., are excellent and usually may be had on the market at a few dollars per ton premium.

In certain instances a low phosphorus content is desired and to have long furnace manipulation it is often economical to melt down stock. Similarly, a supply of wash metal should be on hand for recarbonizing purposes, being far preferable to other materials, especially toward the end of a heat, when the opening of a door may be attended by adverse results, from the air being allowed to enter and fill the furnace.

Usually the great value of alloyed steel castings is found only in those castings which have been properly heat treated, such procedure bringing out to the highest degree the beneficial results of the alloy. Consequently, as all these steels are to have a finishing treatment more care must be exercised to prevent blowholes, and nonmetallic inclusions, as such faults manifest themselves in many disastrous ways, especially during the quenching operations.

Correct heat treatment requires regularity of chemical composition, making the services of a chemist an absolute necessity. As a well equipped laboratory usually is an important part of the modern steel foundry the requirement for a chemist is not out of the ordinary.

### *Making Nickel Steel*

Of the different alloys being used for alloying with iron for commercial castings, nickel ranks among the most important. Nickel confers on the steel certain properties, among the most important being a higher elastic limit and tensile strength without decrease in ductility. It alloys in all proportions with iron, this combination occurring at rather high temperatures, between 1500 and 1600 degrees Cent. Nickel tends to check segregation, probably by its ability to raise the melting point of the steel constituents to the point where solidification becomes more uniform than on plain carbon steels. Nickel steels, especially those of the higher percentages are subject to blowholes and the greatest care must be used to eliminate them before pouring as such defects are difficult to weld properly. It is most difficult, if not impossible, to weld nickel steel containing over 4 per cent nickel. Due to its quick setting characteristics, this class of metal is likely to contain laps and seams, requiring considerable attention to pouring temperatures, and speed of flow into the mold.

Nickel steel castings are rugged, standing an abnormal amount of abuse before failure. Consequently, they find extremely wide use in classes of work where a high elastic limit is desired, or where a metal with high resistance to shock is required. In many instances nickel steels are used where a certain specified strength is desired with a minimum of weight, their high tensile qualities enabling nickel steel to fill the specification with a casting of lighter section than otherwise would be required.

Three classes are widely specified for the ordinary commercial grades of nickel steel castings. The classes are divided into those containing from 1 to 1.5 per cent nickel; those from 2 to 2.5 per cent; and those from 3.25 to 3.50 per cent. Each class is made with carbon to suit, generally ranging from 0.15 to 0.45 per cent. While other percentages of nickel are in use, such as the 4 and 5 per cent grades, they are in the minority. For special purposes, nickel steel mixtures containing up to 36 per cent nickel are used, but these are specialties made only in shops primarily intended for their manufacture, similarly to manganese steel.

Nickel is difficult to oxidize from steel, making its melting simple. Either the acid or the basic process can be used to advantage, both on remelting nickel steel scrap and in the manufacture from carbon steel scrap. Comparative advantages of the two processes will be the same as those outlined for melting carbon steel.

#### *Acid Furnace Practice*

The best method of adding the nickel is to mix it in with the charge, either in the form of nickel pig, or shot. As soon as the heat has melted, it is checked for carbon by the chemist. Little information can be obtained from the appearance of a fracture on nickel steels, and thus

judging of the carbon by this method is so uncertain that its use should not be allowed.

Nickel may be added quantitatively as there will be practically no loss entailed during melting. The heat can be regulated for carbon and manganese according to the chemist's analysis, the best method of adding the carbon being in the form of wash metal, enough nickel being added to compensate for this addition in weight.

The slag should be manipulated exactly as if a heat of carbon steel was being made, and when the familiar yellowish-green color, with proper viscosity is obtained, the metal is ready to pour, providing the temperature is sufficiently high.

Alloys such as manganese and silicon may be added in various ways, but the best results are obtained by finishing all the alloy steel in the furnace. As soon as the metal becomes rather hot, the slag is thickened by the addition of sand, and the metal held until sufficient silicon has been reduced to furnish adequate solidity in the mold. This is a matter of experience and should not be attempted by an inexperienced melter. He should add his manganese to the furnace and the silicon to the ladle in fine pieces until he is sure that he can judge the silicon properly in a reduced test. This period of reduction generally will take from 10 to 12 minutes, depending upon the temperature of the metal, the character of the slag, the size of furnace and the power input. Usually it is different for each installation.

### *Heat Metal High*

If any alloys are added to the ladle, the metal should be heated higher than is ordinarily practiced that thorough assimilation may be assured. The metal should always be held in the ladle for at least five minutes, and ten if possible, to avoid any possible chance of slag remaining in the steel. If the heat is poured under a thick,

viscous slag, the chance of an inclusion is small, any small amount which is trapped during pouring rising to the surface when the steel is held in the ladle.

Best results are to be obtained by the use of a bottom pour ladle, and the metal should be *hot poured*. A regular stream must flow into the mold, and the metal should be sufficiently hot to run without any lagging, or laps and seams will result.

Remelting nickel steel scrap offers no particular difficulty aside from the general considerations governing the manufacture of any high grade metal. Nickel will not oxidize out of the scrap, so there need be no worry about analysis if proper calculations are made at the start of the heat. Should the carbon come down high it may be lowered by boiling with oxide, ore being preferable to scale for such purpose, and the heat finished in the ordinary manner.

Occasionally, a heat of nickel steel will go wild in the furnace, and if it contains a high percentage of nickel it will be extremely difficult to deoxidize. The ordinary classes of deoxidizer such as manganese, silicon, titanium, vanadium, etc., will have no effect, even though added in considerable excess. However, two metals will quickly degasify nickel steels. These are aluminum and magnesium. Aluminum if added in excess, has the undesirable property of making the steel much harder than usual and if used, great care must be exercised. On the other hand, magnesium will give the desired results with a smaller amount used. A supply of this metal should be on hand in shops making nickel steels.

#### *Use of Magnesium to Kill the Heat*

In a wild heat, the metal should be brought up to its proper composition in carbon, manganese, and silicon, these elements being slightly higher than desired. As the heat pours from the furnace small pieces of stick mag-

nesium should be added to the stream flowing over the furnace spout. The ladle should be held until foaming of the slag or gassing ceases, when the metal may be poured. No figures as to the quantity of magnesium required will be given, as this depends strictly upon the degree of wildness, the amount required ranging from an ounce to a pound, per ton of steel. Heats killed in such manner never should be used for castings requiring extremely high quality.

### *Melting Basic Steel*

Basic furnace practice on nickel steel follows closely the practice outlined previously. The nickel may be added either with the charge, or after the heat has melted. The bath and slag should be brought to the proper conditions of temperature and carbide state, the manganese and silicon added and the heat poured.

In the basic steel about two pounds of pulverized fluorspar per ton of metal should be added to the bottom of the ladle before pouring. Fluorspar has the ability to combine rapidly with any slag in the metal, lowering its melting point so that it makes its way quickly to the surface. A few shovels of burned lime always should be thrown on the top of the ladle to thicken this slag. This should be covered with a little coke to make it retain its reducing character during the period of pouring.

The amount of slag to use in basic operation will be determined by the percentage of sulphur which it is desired to eliminate. Priestley, in *Blast Furnace and Steel Plant*, Jan. 1922 gives some interesting analyses covering electric furnace slags from nickel steel heats, together with the corresponding analysis of metal. \*

The quantity of slag used was approximately 3 per cent of the weight of the metal, the bath being held under this carbide condition from 3 to 5 hours. The product was used in making armor steel. The preliminary percentages of sulphur contained in the metal averaged 0.02

per cent. The analyses given by Priestley are shown in Table XXXII.

From these figures it may be seen that the slags are in no particular different from those found on carbon steel operations.

### *Finishing Heats*

In a shop specializing in the manufacture of alloy steel castings, the practice of deoxidizing under air tight conditions should be adopted, not only on nickel steels, but

Table XXXII

ANALYSES OF NICKEL STEEL SLAG									
Heat	SiO <sub>2</sub>	Fe	Al <sub>2</sub> O <sub>3</sub>	Mn	CaO	MgO	P	S	CaC <sub>2</sub>
1.....	15.10	0.64	1.98	0.27	58.24	16.13	0.02	0.28	1.23
2.....	8.16	0.70	3.32	0.11	64.01	16.98	0.07	0.28	1.14
3 ...	11.97	0.66	1.74	0.53	57.95	14.53	0.08	0.19	0.97
4 ...	9.20	0.58	4.39	0.40	61.76	12.77	0.04	0.36	1.31
5 ....	4.32	0.74	2.63	0.14	63.11	16.21	0.02	0.39	1.30
6 ...	17.60	0.49	3.26	1.05	58.32	13.28	0.03	0.34	1.33
CORRESPONDING METAL ANALYSES									
Heat	C		Mn	Si	Ni	P	S		
1.....	.....	0.32	0.71	0.25	0.36	0.022	0.009		
2.....	.....	0.36	0.74	0.24	3.03	0.013	0.008		
3...	.....	0.29	0.74	0.24	2.78	0.010	0.007		
4...	..	0.35	0.71	0.20	0.31	0.013	0.008		
5..	.....	0.38	0.67	0.21	2.97	0.010	0.008		
6..	....	0.30	0.78	0.22	2.83	0.013	0.010		

on all of the alloyed heats. At first, it will require considerably experimenting to determine accurately the carbon pickup from a certain amount of carbide slag held a specified time in the furnace. However, this is determined easily and results made under similar conditions will average close. From the heat records, the weight of slag required to eliminate a specified amount of sulphur, and to thoroughly deoxidize the metal may be determined. From checking the carbons closely by taking tests every few minutes, the average pick up of this element over the finishing period can be obtained.

The next step is to finish the carbon adjustment to the point where the contained analysis, plus this average



pickup, will give an analysis of the desired figure. Then the final slag is added, a good dusting of coke added, and the doors closed and all openings tightly sealed with a luting of mud or clay. Soon the furnace will begin to *snow* slightly, and the openings around the electrodes gradually will build up with the soot to the point where the furnace is absolutely air tight. Then the heat is held for the determined time, when the final test can be taken and the metal tapped. Steel of unusual quality is made by this method, and is regular in its chemical composition. There is no question but that this absolute elimination of oxygen from any entering air results in metal of superior quality. Eliminating nitrogen from the furnace also may be one of the reasons for this improvement as in the presence of such an intense arc the fixation of nitrogen, and its attendant absorption in the steel, is a point which is slightly probable. It is well known that this gas in steel has as much influence, if not more, than oxygen in lowering the quality of the metal. This point is well illustrated by the superior results from steel in which part has been treated with titanium, vanadium, or uranium, their greatest value lying in the fact that they may have the power of removing this nitrogen.

It will be necessary to determine this carbon pickup for several weights of slag, as the volume of slag used will change, depending upon the amount of oxidation the metal has experienced before its finishing. A heat made of clean steel will become perfectly sound in about an hour under a 3 per cent lime slag, heavy in carbide, while one of rather dirty scrap may require two hours under a 5 or 6 per cent slag. However, these points will take care of themselves in any well supervised shop. They are mentioned merely as a point of interest.

While 1 per cent of nickel will raise the tensile strength and elongation about 4000 to 6000 pounds per square inch over a plain steel of corresponding carbon

content, with no lowering of the elongation, bend, or reduction of area, this ratio holds only up to about 5 per cent nickel, where the increase would amount to only a

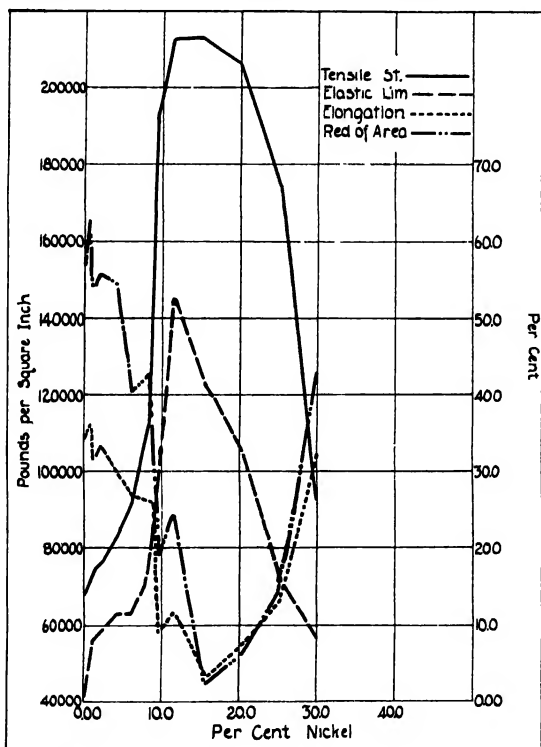


Fig. 42—Changes in Properties Due to the Addition of Nickel. The Carbon Averages 0.17 Per Cent and the Manganese, 0.82 Per Cent and the Specimens Were Unannealed

maximum of 30,600 pounds per square inch. When it is considered that a simple treatment will give the same re-

sult on a 2 per cent nickel steel, as on a natural 5 per cent alloy, it is readily seen why all such castings are heat treated. If there was no increase in physical qualities,

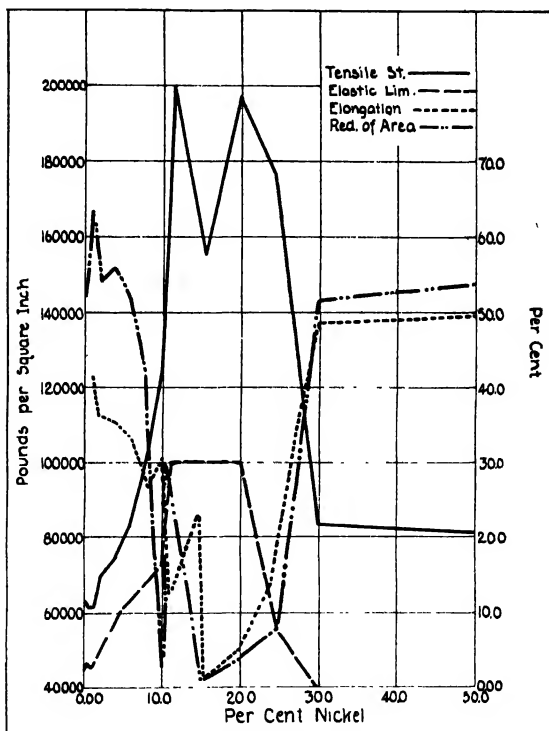


Fig. 43—Annealed Specimens of Nickel Steels, Averaging the Same in Carbon and Manganese

the question of cost would determine this point, but the vast difference between raw and treated castings is an

item far superior to that of the added cost of a few per cent of nickel.

Nickel has the same effect upon steel as carbon, although to a greater degree. It lowers the transformation points. For the ordinary grades of nickel steel used in casting work, from 1 per cent nickel up to 4 per cent, 0.50 per cent nickel will lower the  $Ac_1$  range about 10 degrees Fahr. and the  $Ar_1$  range on cooling about 20 degrees Fahr., from those of similar contents in plain steels.

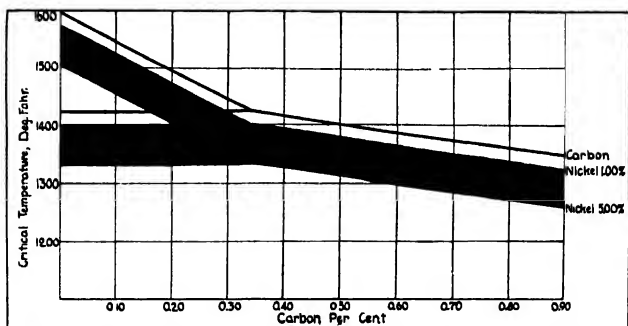


Fig. 44—Effect of Varying Amounts of Nickel on the Critical Temperature of Steels With Varying Carbon Contents

The approximate critical temperatures of these steels run from about 1325 to 1310 degrees Fahr. ( $Ac_1$ ), 1250 to 1230 degrees Fahr. ( $Ar_1$ ) for the 1.00 per cent nickel to about 1250 to 1270 degrees Fahr. ( $Ac_1$ ), 1100 to 1120 degrees Fahr. ( $Ar_1$ ) for the 4.00 per cent nickel, depending upon the differences in miscellaneous composition, carbon, manganese, etc.

Nickel steels offer a distinct difference from plain carbon steels when heated above the critical points for any length of time, carbon steel tending to grow in grain size while nickel steels tend to become finer and closer in grain. Of course, this statement does not mean that such super-

heating is desirable, as heating for continued periods at such temperatures naturally will weaken the metal. Such a characteristic is a greater advantage in handling work of large size, or heavy section, as the time of soaking may be prolonged, during which period the grain is being refined to a marked degree, a point directly the opposite to the plain carbon steels. While this added heating tends slightly to raise the cost of treating, this would be a secondary consideration when dealing with products of the

**Table XXXIII**  
TESTS OF BASIC NICKEL STEEL

Treatment	Tensile St. lbs. sq. in.	Elastic limit lbs. sq. in.	Elonga- tion per cent	Red. area per cent
As cast .....	85,000	46,000	20.0	48.0
Annealed from 1450 degrees Fahr. ....	83,500	43,600	24.4	53.2
Water quenched from 1400 de- grees Fahr. ....	93,000	74,600	20.7	66.4
Drawn back to 900 degrees Fahr. ....	102,640	81,100	19.8	71.7
Water quenched from 1400 de- grees Fahr. ....	137,000	113,800	13.4	58.8
Drawn back to 550 degrees.....	143,000	106,400	12.9	55.7

highest quality. Figs. 42 and 43 show the changes in a steel due to increasing its content of nickel.

Fig. 44 shows the manner in which certain percentages of nickel affect the critical temperatures of steels of varying carbon contents.

On small size castings, the general practice is to heat slightly above the upper critical range, allow them to soak until the heat is diffused thoroughly throughout the piece or pieces being treated, withdraw from the furnace, and quench in either air, oil or water, depending upon the shape of the piece, and the desired specifications. These pieces are then drawn back to the temperature necessary to give the desired toughness. On larger sized castings, it often is necessary, and usually desirable, to give a double quench that the transformation may be com-

plete, nickel having a tendency to retard this action. Brinell hardness numbers will range from about 175 on the annealed specimens of medium steels, to 400 on some of the harsher quenches.

### *Properties of Nickel Steel*

Tests made on nickel steel indicate clearly the influence of the methods of heat treatment. A bearing was cast from metal analyzing carbon, 0.23 per cent; manga-

Table XXXIV  
TESTS OF ACID NICKEL STEEL

Treatment	Tensile St. lbs. sq. in.	Elastic limit lbs. sq. in.	Elonga- tion per cent	Red. area per cent
As cast .....	82,000	47,000	12.3	9.8
Annealed from 1450 degrees Fahr. ....	85,550	50,000	19.2	21.6
Air quenched from 1500 degrees Fahr. ....	94,100	57,000	13.1	12.7
Air quenched from 1500 degrees Fahr. drawn back to 1300 degrees Fahr. and held in furnace 5 hours.....	87,200	51,300	20.6	22.0
Air quenched from 1500 degrees Fahr. drawn back to 1300 degrees Fahr. and held in furnace until rather cold..	93,350	52,100	28.0	41.5
Air quenched from 1500 degrees Fahr. drawn back to 1300 degrees Fahr. and quenched in hot water. Drawn back to 1300 degrees Fahr. and cooled in furnace. ....	92,750	53,000	34.0	51.3

nese, 0.75 per cent; silicon, 0.21 per cent; nickel, 1.53 per cent; phosphorus, 0.035 per cent. and sulphur 0.02 per cent. The steel was made in the basic furnace.

When first cast, this metal showed a tensile strength of 77,000 pounds per square inch with an elongation of 24 per cent and a reduction in area of 32.6 per cent. The elastic limit was 43,000 pounds per square inch. When annealed to 1500 degrees Fahr. and cooled in the fur-

nace, the tensile strength increased to 97,400 pounds per square inch, the elastic limit to 54,200 with an elongation of 26.2 per cent and a reduction in area of 41.9 per cent.

When quenched in air blast from 1500 degrees Fahr. and drawn back to 900 degrees Fahr., the tensile strength decreased, but the elastic limit, elongation and reduction in area were increased.

When treated as previously, but quenched in oil and drawn to 550 degrees Fahr., the tensile was increased to 112,000 pounds per square inch, the elastic limit to 98,000 pounds per square inch, but the elongation dropped to 19.0 and the reduction in area to 37 per cent.

Some tests upon nickel steel with an average carbon from 0.25 to 0.30 per cent; manganese, 0.60 to 0.70 per cent, silicon, 0.20 to 0.25 per cent; nickel, 3.25 to 3.50 per cent, as made in the basic furnace are shown in Table XXXIII.

Tests made on metal produced in the acid furnace from a clevice casting weighing approximately 600 pounds, the maximum thickness of a section of the arm from which the tests were taken being three inches are shown in Table XXXIV. The metal analyzed: Carbon, 0.27 per cent; manganese, 0.83 per cent; silicon, 0.24 per cent, and the nickel, 1.84 per cent.

Detailed logs of furnace operations on nickel steel using both the acid and the basic lined melting hearths and with different types of charges are shown in Appendix Tables 17, 18, 19 and 20.

## XII

### CHROMIUM, NICKEL-CHROMIUM, MOLYBDENUM, VANADIUM, ZIRCONIUM AND SILICON STEELS

**C**HROMIUM, like nickel, has no powers of deoxidizing a bath of metal, but has the faculty of conferring great hardness on the steel with no decrease in the ductility. For this reason it finds its widest use in classes of casting where a metal of maximum hardness is desired, together with a certain amount of toughness. For such work as crusher jaws, wearing plates, parts subject to abrasion, and rolls, it has no equal. While it has not the resistance to abrasion that manganese steel has, it can be made much harder, so that it can be used in instances where manganese steel is unsuitable, due to its tendency to flow under strain. One of the new lines in which chrome steel is finding wide use is in the manufacture of drilling tools, for oil well operations, where the hardness of the metal is its chief asset, being used extensively for such parts as tongs, underreamer bits and bodies, and fish-tail bits.

In the manufacture of chrome-steel castings three types probably cover 99 per cent of the production. These include steel with 0.50 per cent chromium, with 1.00 per cent, and with 1.50 per cent. Of these the two lower contents find the widest use. The carbon content will change according to the type of casting, and its intended use, ranging from approximately 0.25 per cent on some oil well tools, to as high as 0.90 per cent on crusher jaws and rolls.

By far the most common analysis made is that of carbon, 0.40 to 0.50 per cent, with a chromium as close to 0.50 per cent as possible. This is approximately of equal strength to a high class carbon steel forging, and



has the added advantage of greater hardness, with none of the brittleness associated with the metals of high carbon content.

Chromium differs greatly from nickel in its properties of combining easily with oxygen. Consequently, greater care must be exercised in making such alloying additions. It is used in a manner similar to manganese or silicon, the latter closely resembling chromium in its speed of oxidation. Therefore, while chrome steel may be produced satisfactorily in the acid furnace such operation, if regular, is rather expensive because when the shop returns are remelted, all of the chromium contained is oxidized out and lost. In shops where a heat of chrome steel is of rare occurrence the acid furnace proves suitable, but in shops specializing in making chrome castings the usual operation is basic.

In melting chrome steel the same procedure is followed as with a heat of carbon steel, with only slight differences. Naturally, possessing a high degree of oxidation, it would be foolish to add ferrochromium to a bath of oxidized metal. Therefore, the slags must be thickened and after the silicon has started to reduce, the ferrochrome may be added. This will be five or ten minutes before the heat is ready to pour, and if possible, the chrome should be added not over five minutes before the heat is tapped. To obtain such conditions, and at the same time keep the silicon content at the proper figure, requires considerable judgment as to methods of manipulating the slag to attain the required conditions. The ferrochrome should be moistened so as to kick through this slag, and it is good practice to rabble the bath well to assure that the chrome has actually penetrated into the steel.

Additions of chromium should be approximately 10 to 15 per cent higher than is desired in the finished steel, that compensation may be made for the higher loss.

Basic furnace operation will be identical to carbon steels, with the exception that the ferrochrome should be added after the carbide slag has formed, and should be allowed at least 20 minutes under such a slag before tapping the furnace. The losses are lower than on acid operation, and 10 per cent additional chrome over the specification will be satisfactory. These heats should not be poured if the slag shows a faint apple green, as this is a sure indication that the slag still contains a con-

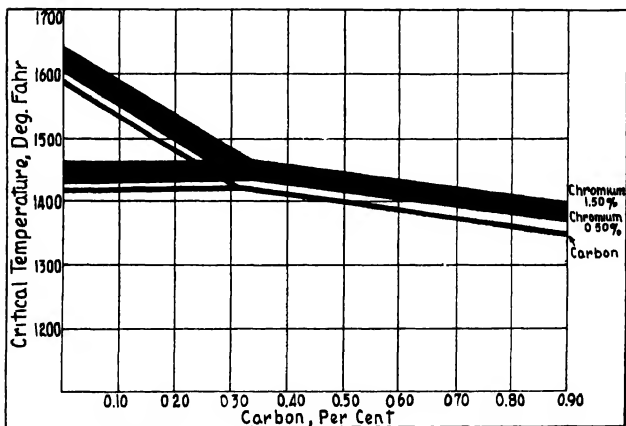


Fig. 45—Changes in Critical Temperatures Are Caused by Variations in Chromium Content

siderable amount of chromium. In such a case more lime and coke should be added, and reduction kept up until the slag shows its true gray, powdering conditions.

Chrome steels of the higher percentages always should be finished under heavy reducing conditions, the furnace being kept closed with all openings as tightly sealed as possible. For high grade steels containing both high carbon and chromium it is permissible to add the chromium

an hour before the pour, after the metal has reached a solid state, tightly seal the doors, and allow the furnace to operate under these air tight conditions until the metal is finished. Table 21 in the Appendix gives furnace logs on chrome steel in both acid and basic hearths.

### *Effect of Chromium*

Chromium acts like nickel in changing the critical points of steels, but in the opposite direction. It causes the temperatures to become slightly higher than those of plain carbon steels of the same carbon content. Chromium is exactly the opposite of nickel in other properties.

Table XXXV  
AVERAGE TESTS ON CHROMIUM STEEL

The steel analyzed: Carbon, 0.60 to 0.70 per cent; chromium, 0.50 to 0.75 per cent, and the other constituents were standard.

Treatment	Tensile strength pounds	Elastic limit pounds	Elonga- tion per cent	Red. area per cent
Quenched at 1500 deg. Fahr., drawn back to 1300 deg.....	79,000	65,500	34.4	66.6
Drawn back to 1050 deg. Fahr..	100,600	94,300	20.1	60.0
Drawn back to 800 deg. Fahr ..	114,000	103,400	14.3	54.4

Overheating it for prolonged periods, rapidly deteriorates its strength and resistance to shock. For this reason, a double quench gives superior qualities to chromium steels. Chromium steels are capable of taking great hardness, without a corresponding decrease of toughness, this hardness coming directly from the double carbide of iron and chromium. Consequently, all such steels must be softened according to the amount of machining which is to follow.

Fig. 45 shows the changes in the critical temperatures caused by different chromium contents.

The general treatment on chromium steels is similar to that on the alloys containing nickel. It involves a quench from above the critical point, which either a draw

back in the air, or a reheat and quench at the lower temperature.

An example of the treatment is shown in Table XXXV.

### *Nickel With Chromium*

Nickel chromium steels probably represent one of the best general types of steel for heat-treated castings. When treated, this metal shows the beneficial result of the toughness and ductility of the nickel, together with the increased hardness and cohesion of the chromium. The best results are obtained by having a certain ratio of the two alloys, generally  $2\frac{1}{2}$  parts of nickel to 1 part

Table XXXVI

#### AVERAGE TESTS ON NICKEL-CHROME STEEL

The analysis of the metal averaged as follows: Carbon, 0.30 to 0.40 per cent; nickel, 1.30 to 1.70 per cent; chromium, 0.50 to 0.70 per cent. The results cover approximately 100 tests.

Treatment	Tensile strength pounds	Elastic limit pounds	Elonga- tion per cent	Red. area per cent
Annealed from 1500 deg. Fahr.	66,700	37,000	17.5	25.8
Annealed from 1350 deg. Fahr.	65,000	32,600	30.1	54.3
Quenched from 1500 deg. Fahr., drawn back to 1000 de. Fahr.	90,000	65,000	23.9	61.6
Quenched from 1550 deg. Fahr., drawn back to 900 deg. Fahr.	84,400	50,050	26.5	57.7

of chromium, thus giving rise to the common ratios such as 2.50 per cent nickel, 1.00 per cent chromium; 1.50 nickel, 0.60 chrome; 3.50 nickel, 1.25 chrome, etc.

These steels are manufactured by combining the methods used for either plain nickel or chromium steel. If it is remembered that nickel is difficult to oxidize, and chromium is easily oxidized, no trouble should be encountered. Basic operation is preferable, due to its ability to conserve the alloys in the steel. The metal is melted under ordinary circumstances, the alloys being added after the proper slag conditions have occurred.

The same precautions must be followed as in making

a plain alloy steel, such as superheating to allow better diffusion of the nickel.

The heat treatment will depend upon the character of the casting, and the results desired. The general treatment is to quench in oil from a temperature higher than the critical point, and draw back to the specification desired. For rigid or high specifications, a double quench is preferred. Quench from about 200 degrees Fahr. above the critical point, re-quench from just above the critical point, and draw back to the toughness desired. Some

Table XXXVII  
AVERAGE TESTS NICKEL-CHROME STEEL

The analysis of metal averaged as follows: Carbon, 0.35 per cent; manganese, 0.82 per cent; nickel, 1.95 per cent; chromium, 0.66 per cent; silicon, 0.36 per cent; sulphur, 0.022 per cent; and phosphorus, 0.011 per cent. These results were given in the *Iron Trade Review* of Aug. 23, 1923.

Treatment	Tensile strength pounds	Elastic limit pounds	Elonga- tion per cent	Red. area per cent
1500 water quench draw back to 1200 deg. Fahr. ....	130,000	113,300	14.5	29.5
Air cooled .....	104,750	75,000	21.0	48.3
Furnace cooled from above draw .....	105,800	92,650	23.5	52.0
1500 water quench, draw back to 1150, slow cool in furnace	105,750	91,700	23.0	52.0
1500 water quench, draw to 1150, quench from draw.....	107,000	89,000	21.0	51.1
Do. as above .....	107,050	89,500	23.5	53.9

figures on these classes of steels are given in Tables XXXVI and XXXVII.

#### *War Demand Aids Molybdenum Alloy*

The stress of war gave impetus to the use of molybdenum in steels. The use of molybdenum was associated with great resistance to impact, excellent strength, accompanied by good elongations, and high reduction of area.

However, in the foundry, the use of this metal in steel alloys never has been large, probably from the fact

that specifications could be met with more common alloys than for any other reason. Recently, molybdenum has found rather extensive use in large castings, where resistance to shock and great toughness are desired, one particular instance being in the breaking-down rolls for rolling mills.

Its manufacture offers no differences from that of any other alloy steel. Molybdenum has similar properties to nickel, those of being impervious to oxidation. Consequently it may be made in either the acid or basic furnace, the alloys being reclaimed in either process. The additions of the alloy may be made in the form of ferromolybdenum. This may be added at any time

Table XXXVIII  
AVERAGE TESTS OF MOLYBDENUM STEEL

The analysis of the metal was approximately as follows: Carbon, 0.35 per cent; molybdenum, 0.40; nickel, 1.90; chromium, 0.80; manganese, 0.85.

Treatment	Tensile strength pounds	Elastic limit pounds	Elongation per cent	Red. area per cent
Air cooled from 1450 deg. Fahr.	162,400	130,000	3.5	3.9
Annealed from 1450 deg. Fahr.	140,400	104,000	13.0	24.4
Air cooled from 1450, drawn back to 1250 .....	119,450	90,000	17.0	25.1
Annealed from 1450, drawn to 1250 .....	101,100	60,150	17.5	33.7

after the bath of metal has become thoroughly molten, or in the basic process it may be added in the form of calcium molybdate, in which form it tends to build its own slag. Having a higher melting point than any other alloy, except tungsten, molybdenum requires high pouring temperatures to insure its thorough diffusion throughout the steel. Therefore, additions must be made a sufficient time before the tap to insure the completion of its fusion and consequent solution.

The figures shown in Table XXXVIII were obtained on a casting containing this element.

### *Vanadium Steels*

Vanadium finds rather extensive use in making castings to be heat treated. It is used alone, in combination with nickel or chromium and also with combination of the two. The usual percentage used is sufficient to allow a final vanadium analysis in the steel of from 0.15 to 0.25 per cent, generally running about 0.18 per cent.

Vanadium will increase the strength and ductility of any grade of steel but there is a considerable difference of opinion as to the exact effect of this element. Some writers make the claim that it is the alloy itself to which these increased figures are due, and explain it by the action of vanadium diffusing the carbide structure in the steel, giving a refinement of the grain throughout the mass. Other writers make the claim that its worth is strictly one of powerful deoxidizer, stating that its scavenging action manifests itself on oxygen and nitrogen. By removing these gaseous elements, it gives the steel, which is considerably denser than the ordinary product, its increased strength and toughness which is the main reason for the superior tests.

The author recently has completed a series of tests covering the use of vanadium in cast steel, both on the electric and open hearth furnace. From the results of these tests, vanadium is shown to have no power as a deoxidizer. It gives its superior results by its action on the carbon. The author made a large number of tests taking analyses for manganese, silicon and vanadium at various points during the heat. It was found that the loss of manganese and silicon increased as the pouring of the heat progressed, while there were no indications of any change in the vanadium content.

It was found that on a 25-ton heat, the silicon loss

during the pour ranged from 0.08 to 0.12 per cent, while that of the manganese ranged from 0.04 to 0.08 per cent. However, the vanadium test was constant throughout this period. To obtain 0.18 per cent in the steel it was necessary to add only 0.20 per cent of vanadium. The loss of this alloy averaged approximately 10 per cent and was due to that which was lost through mechanical mixture with the slag. When vanadium is used, it will be found that the recovery of silicon is much higher than in ordinary steels, which in a way gives rise to the oxidizing claims.

The author found that this was due directly to the proportion of silicon in the vanadium alloy, which amounted to approximately 10 per cent, and when this was considered, the silicon losses were the same as they would be on a soft steel heat. After the proportion of vanadium drops below 0.15 per cent, the tensile strength and elastic limit is considerably lower, while there appears to be no advantage in running the steel past 0.25 per cent vanadium. With a steel of approximately 0.25 per cent carbon, there is only enough free carbon to take care of this 0.18 per cent vanadium and when vanadium is added above that figure remains in the steel as an inert element, it represents but an added cost with no advantage.

Vanadium is a metal with a higher fusing point than those more commonly used and consequently must be given a slightly different treatment than either manganese or silicon.

In acid and basic open-hearth furnaces, this alloy was added at the spout using it crushed to the size of  $\frac{1}{2}$ -inch mesh. In the basic electric furnace, this alloy was added approximately a half hour before tapping, while in the acid furnace it was added directly in the ladle. While this adding in the ladle is not as good a practice as it might be, the acid steel is poured so hot that com-



plete assimilation is assured and no evidences of segregation were found. If the acid steel was poured rather cold, the vanadium was added to the furnace; being slightly moistened and the slag thoroughly rabbled immediately after its addition. Practically all of the vanadium may be reclaimed from the scrap when melting in the basic furnace and approximately 50 per cent in the acid furnace.

The following tests represent the result of vanadium steel as made in the acid electric furnace. The metal analyzed carbon, 0.30 per cent; manganese, 0.75 per cent; phosphorus, 0.028 per cent; sulphur, 0.052 per cent; silicon, 0.35 per cent and vanadium, 0.20 per cent. The test results follow:

#### Test Bar No. 1

Heated in 1700 degrees Fahr. Held at temperature 1½ hours.  
Cooled in air

Tensile	98,300 pounds
Elastic limit	62,000 pounds
Elongation	24 per cent
Reduction	39.7 per cent
Fracture	½ cup, silky

#### Test Bar No. 2

Same as No 1, but cooled in furnace.

Tensile	92,250 pounds
Elastic	56,100 pounds
Elongation	25 per cent
Reduction	40.7 per cent

#### Test Bar No. 3

Heated to 1700 degrees Fahr. Held at temperature 1½ hours.  
Cooled in air. Heated to 1400 degrees Fahr. Held at temperature 1 hour and 30 minutes. Cooled in air.

Tensile	92,250 pounds
Elastic	60,500 pounds
Elongation	26.5 per cent
Reduction	47.2 per cent

#### Test Bar No. 4

Same as No. 3, but allowed to cool in furnace after draw.

Tensile	89,150 pounds
Elastic	54,600 pounds
Elongation	27.5 per cent
Reduction	52 per cent

**Test Bar No. 5**

Heated at 1700 degrees Fahr. Held at temperature 1 hour.  
Cooled rapidly in air.

Tensile .....	103,000 pounds
Elastic .....	70,000 pounds
Elongation .....	20 per cent
Reduction .....	36.6 per cent

**Test Bar No. 6**

Same treatment as No. 5.

Tensile .....	101,650 pounds
Elastic .....	69,720 pounds
Elongation .....	20.8 per cent
Reduction .....	35.9 per cent

**Test Bar No. 7**

Heated to 1700 degrees Fahr. Held at temperature 1 hour.  
Cooled in furnace.

Tensile .....	92,750 pounds
Elastic .....	56,500 pounds
Elongation .....	25 per cent
Reduction .....	45.4 per cent

A second series of bars was tested. These had the following analysis: Carbon, 0.42 per cent; manganese, 0.93 per cent; phosphorus, 0.025 per cent; sulphur, 0.047 per cent; silicon, 0.32 per cent; vanadium, 0.21 per cent. The results of these tests follow:

**Test Bar No. 1**

Heated to 1650 degrees Fahr. Held 2½ hours. Air cooled.

Tensile .....	117,900 pounds
Elastic .....	81,000 pounds
Elongation .....	11.5 per cent
Reduction .....	15.2 per cent

**Test Bar No. 2**

Heated to 1660 degrees Fahr. Held 2 hours and air cooled.

Tensile .....	112,000 pounds
Elastic .....	80,500 pounds
Elongation .....	12.5 per cent
Reduction .....	17.7 per cent

**Test Bar No. 3**

Same as No. 2, but reheated to 1450 degrees Fahr. Held 2 hours and air cooled.

Tensile .....	98,800 pounds
Elastic .....	64,500 pounds
Elongation .....	15 per cent
Reduction .....	19.8 per cent

**Test Bar No. 4**

Heated to 1700 degrees Fahr. Held 2 hours and air cooled.

Tensile .....	110,560 pounds
Elastic .....	77,250 pounds
Elongation ..	12.9 per cent
Reduction .....	18.2 per cent

**Test Bar No. 5**

Same as No. 4 but reheated to 1450 degrees Fahr. Held 2 hours and air cooled.

Tensile .....	97,750 pounds
Elastic .....	65,200 pounds
Elongation ..	15.3 per cent
Reduction .....	19.6 per cent

**Test Bar No. 6**

Forged down to  $\frac{3}{4}$ -inch round from a 2-inch square bar before being reheated. Heated to 1660 degrees Fahr. Held 2 hours and cooled in air.

Tensile .....	106,250 pounds
Elastic .....	75,800 pounds
Elongation ..	16 per cent
Reduction .....	19.1 per cent

**Test Bar No. 7**

Same as test bar No. 6 but drawn at 1450 degrees Fahr. Held 2 hours and air cooled.

Tensile .....	98,260 pounds
Elastic .....	66,260 pounds
Elongation ..	16.8 per cent
Reduction .....	20.1 per cent

The fractures from annealing lugs or castings poured from vanadium steel give an extremely fine grain and dense structure. A carbon steel carrying 0.25 per cent carbon with vanadium gives a similar appearance to 0.40 or 0.45 per cent plain carbon steel.

Authors differ as to the proper temperature at which to treat these steels. These range from 1550 degrees to 1900 degrees Fahr. The author finds that a temperature of from 1675 degrees to 1700 degrees offers probably the best temperature for the ordinary soft carbon steels.

As the influence of vanadium becomes better known, its use will increase for equal results may be obtained using this element as with nickel-chrome steels, with the

added advantage that the vanadium steel will be considerably cheaper per pound of metal.

### *Zirconium Steel*

Zirconium has assumed prominence recently through extensive experiments conducted to determine its favorable or unfavorable effect upon steel. The partial results of this series of tests has been described by F. M. Becket in the *Iron Age* of May 10, 1923. He states as follows:

Zirconium has greater affinity for oxygen than has silicon and, due to this fact, increased silicon recoveries are made in finished steels by the use of zirconium-silicon alloys. This greater recovery of silicon is marked when an alloy of 35 per cent zirconium is used. For example, in a series of 40 heats of basic electric furnace steel, an average recovery of 98 per cent of the silicon was realized as compared to a recovery of 84 per cent for ordinary ferro-silicon added under identical conditions and in equivalent percentages of added silicon to duplicate ladles. This particular series resulted in a 56 per cent recovery of zirconium, a ladle addition of 0.15 per cent being made in each case.

The rate of the reducing action of zirconium on the impurities present in molten steel is not only more rapid than that of silicon, but zirconium is more efficacious in removing the final traces of oxygen and nitrogen. Zirconium steels exhibit a cleanness which appears to be the result of a more deep seated action than mere combination, such as characterizes the more common deoxidizing agents.

No indication of inclusions of zirconium oxides has been observed in the course of the investigation, all the evidence pointing to the fact that this element forms a fusible slag with the iron and manganese oxides, and rapidly finds its way to the surface of the metal. Minute yellow crystals of zirconium nitride generally are observed in steels which have been treated with zirconium in excess of 0.10 per cent. They are strictly limited in number and represent the residuum of the nitrogen content of the steel which was fixed by zirconium but not slagged off prior to solidification. That these inclusions do not exer-

cise a harmful effect has been shown by tests covering this particular point.

When zirconium is added to steel in excess of 0.15 per cent this element assumes a new role by chemically combining with sulphur to form an acid insoluble compound not detected by the ordinary evolution method of analysis. It has been determined that for basic electric steel practice when the alloy is added to the ladle, every part of zirconium in excess of 0.15 per cent fixes 0.10 parts of sulphur as an acid insoluble zirconium sulphur compound. This chemical combination is as effective for ordinary sulphur analyses as on those containing abnormal amounts of this element.

A 5-ton acid openhearth heat and a 10-ton basic electric heat may be cited as examples of the influence of zirconium on the sulphur. In the former case an addition of 0.27 per cent zirconium lowered the sulphur from an initial percentage of 0.040 per cent to a final value of 0.025 per cent. In the latter 0.22 per cent of added zirconium diminished the sulphur from 0.020 per cent to 0.009 per cent, leaving a residual zirconium content in the steel of 0.15 per cent. Steels containing 0.08 per cent total sulphur have been reduced by ladle additions to a total sulphur of 0.048 per cent.

From the foregoing data it appears that the value of zirconium lies in its powerful action as a scavenger more than its ability to confer advantages by its propensities as an alloy. This element is not, as yet, widely known and later discoveries may prove its value for further uses.

### *Silicon Steel*

Ordinary steel castings contain silicon in amounts varying from 0.25 to 0.35 per cent, although in certain instances either higher or lower percentages may be found. It has long passed as true that steel castings with higher silicon contents than those mentioned would have a tendency to crack and tear badly in the mold, and cause difficulty. That this is a fallacy has been proved by the author many times. Electric furnace heats have

been made with silicons running as high as 1.00 per cent, and no cracked castings have been found where the trouble was due directly to high silicon. It is perfectly true that the steels with a high silicon content offer difficulty if treated in a similar manner to those of the lower percentages, but when a steel of this character is handled properly satisfactory results may be obtained from its use.

The first point noted in handling these steels is the high degree of solidity, which naturally is expected. This gives rise to a higher shrinkage, and the feeding heads must be made larger for a given casting. This also leads to a quicker body shrinkage of the piece, and care must be exercised to allow for this by loosening the heads and gates on large castings after the pour. With these steels, the use of coke filled cores, wood inserts, sawdust fillers, etc., finds constant application as a preventative for tearing and cracking.

The second point noticeable is the fluidity of the metal at apparently low temperatures. This is especially marked when taking tests from the furnace, and noting the time necessary for the skin to form on the metal in the spoon. With the ordinary grade of steel containing low silicon, the steel will remain fluid for probably 30 seconds on a fairly hot heat. With the steels containing higher silicon, the metal will skin in the spoon in a few seconds on exposure to the air, but will pour clean when apparently set. This leads to considerable trouble in ascertaining the proper pouring temperature, the metal either being poured too cold, or extremely hot, both of which cause loss to the foundry.

The third, and most advantageous point in relation to this metal is the wearing quality it gives a steel without any increase in machining difficulty or great decrease in ductility. Consequently, it finds considerable use in classes of work where high resistance to wear is

required, and where machine work on the piece is extensive. Such instances as cut gears, cams, eccentrics, etc., of complicated shape, offer exceptional qualities when cast of this metal. While it does not approach either manganese steel or the more complicated alloy mixtures in length of service, it can be machined readily and does not require heat treatment to bring out its beneficial properties. Further, an entire heat of this metal may be cast, and the other castings poured will give satisfactory service when handled in the ordinary foundry routine.

The best analysis to give the desired results with this steel is about as follows: Carbon, 0.30 to 0.35 per cent; manganese, 0.60 to 0.70 per cent; and silicon, 0.50 to 0.60 per cent. A steel of such analysis will have a tensile strength of approximately 12,000 to 15,000 pounds higher than one with a low silicon content, with a decrease in the elongation of only about 4.00 to 5.00 per cent. The elastic limits of high silicon steel are considerably higher than those to be had on ordinary analyses. The standard bend bars will give exactly the same degree of bend for higher silicon steels as for the lower content, bars of low carbon steel having bent 180 degrees cold, when the silicon analyzed over 2.00 per cent.

With silicons above 0.70 per cent difficulty may be found in welding the minor defects, especially if acetylene is used. The electric arc may be used in welding until the percentage of silicon approaches close to 1.00 per cent. The effect of silicon in any quenching operation may be considered as negative.

High silicon steel may be made either by the acid<sup>\*</sup> or the basic process, the latter giving more regular results. If made by the acid method, the steel is finished according to general acid practice the silicon being added to the furnace a few minutes before the pour, sufficient time being given to assure its thorough assimilation.

Twenty per cent over the required amount usually is added to take care of the oxidation loss, which is high.

If made by the basic process, the heat is finished under a carbide slag, the silicon being added as for ordinary steel, 10 per cent additional being required. A small amount of lime should be added with the silicon to prevent any tendency of the silicon thinning the slag, and to assure its thorough reduction into the metal. Appendix Tables 22 and 23 are logs on silicon steel heats.

The point of greatest difficulty in the manufacture of this metal is judging the proper temperature. The common spoon or skin test is of no value, the metal forming a film directly on exposure to the air, regardless of its temperature. Similarly, pouring over the lip of the spoon and noting the manner in which the steel sets in the chill mold is of no value, the metal setting at once. The steel in the test spoon does not have the mercury-like appearance of low silicon metal, but appears creamy, and shows small, silvery spots over the surface. It looks as if the metal would freeze in the spoon at once, yet on pouring it will leave no vestige of a skull. The most reliable test of temperature is to determine exactly the length of time it takes an ordinary heat to come to pouring temperature after a clean drain from the test spoon, and then run the silicon heat in exactly the same manner. Of course, this will be different for every shop and will be determined largely by the power input to the furnace, and the number of gates which must be poured from the heat. After several trials it becomes easy to judge its temperature from slight variations in the color of the metal. Also it may be determined how many gates may be poured safely. This steel will pour intricate castings at temperatures at which the lower silicon steels freeze.

These classes of steels react in the same manner to heat treatments, as plain steels of a similar carbon content.



# XIII

## GRAY IRON

**A**S THE use of the electric furnace in the manufacture of steel castings became more common, it was natural that its use for melting gray iron should follow. Many electric steel foundries also manufactured iron castings, and when the great refining ability of the electric furnace became known, it was assumed that such a characteristic would materially aid in increasing the quality of the iron itself.

The result of such supposition was a trial of making cast iron by the electric process. It soon was noticed that such a treatment was exceedingly beneficial, and experiments were made to determine exactly the results and direct benefits which would accrue from such a treatment.

The first point of great importance was the ability of the electric furnace to furnish iron at a high temperature. When this is compared with the average cupola practice its manifest advantages can be observed. Cupola operation may be classified by a temperature gradient into three sections:

Those foundries producing iron at 2600 degrees Fahr. or over.

The average foundry with iron at 2500 to 2600 degrees Fahr.

Poor practice with the iron under 2500 degrees Fahr.

As cast iron melts at 2250 degrees Fahr., and freezes at about 2100 degrees Fahr., the practices classified offer molten iron superheated from approximately 200 to 400 degrees Fahr. When it is considered that the average loss in heat of iron from the cupola to the time of actually pouring the mold is about 200 degrees Fahr. it readily is seen that the cupola melting does not heat the iron to high enough temperature. The direct result is to

increase the percentage of lost castings, from such items as misruns, cold shuts, shrinks, etc.

With the electric furnace, the direct opposite to this is the rule. The metal may be heated readily to 2750 degrees Fahr., offering sufficient leeway not only to take care of the lost temperature due to handling on the floor, but to provide sufficient temperature at the mouth of the mold to insure a clean run. Hot iron, poured in a mold, has a much greater chance to give a thoroughly solid casting than one poured at a temperature only a few degrees above the point of solidification. Consequently, superheating the metal is the first great advantage of the electric furnace.

. This is true not only of the standard irons, containing a high percentage of phosphorus, but is equally true of the so-called high strength irons, which are notably difficult to make in the cupola for small or intricate work. With the electric furnace, iron can be poured with ease which would offer great difficulty if made in the cupola.

The second point of advantage is that of being able to reduce the sulphur coincident with superheating, and during the same operation thoroughly to deoxidize the metal. Sulphur is directly accountable for many foundry difficulties, being one of the prime causes of hard spots, dirty inclusions, and weakening of the iron by breaking up the continuity of the structure. It may be one of the causes behind the cracking of certain castings. It is reasonable to believe that a lowering of the sulphur aids the metal by removing some of these causes of trouble. This point has been proved so many times that further comment becomes unnecessary.

The third point observed is the ability to offer metal of uniform grade over any specified period. with absolute regularity. With modern production methods in the machine shops, such an item is of prime importance

and is becoming more widely appreciated. This range of metal passes from the softest irons to those of great strength, made by using large percentages of steel in the mixtures, all of which can be made easily and well in the electric furnace.

Therefore, the main results of electric furnace operation may be classed as follows:

#### SUPERHEATING

Lowers the percentage of lost castings.

Gives castings of better appearance, and greater solidity.

The size of the heads may be lowered due to the great fluidity of the metal.

A considerable saving of iron and labor is affected due to a lowering of the amount of pig and ladle skulls.

The metal enters the mold in a cleaner state, the impurities rapidly tending to clear themselves from this fluid iron, resulting in lower losses from sand and slag spots.

The iron is naturally of a higher quality and considerably stronger.

#### REFINING

Electric melting deoxidizes the iron, which constitutes an advantage as great as if steel were being cast.

The sulphur may be lowered to any desired point with many advantages.

Lower sulphurs require lower percentages of manganese constituting an important saving over an extended period of time.

#### COMPOSITION

Analyses of absolute regularity can be made.

Low phosphorus irons, with their great strength can be melted and cast easily and readily.

Large proportions of steel can be used to give irons of widely varying characteristics.

#### ECONOMIC

Pig iron can be absolutely eliminated from the charges.

Such a scrap as borings may be readily handled with insignificant losses.

The foundry is independent of the quality of the coke supply.

Large pieces impossible of cupola melting may be used with success.

Even with these advantages, the electric furnace is but slowly gaining a foothold in the iron foundry, due to the high initial cost and expense of operation. The average customer is not interested in the quality of his metal, but desires to receive a nice appearing casting at the lowest possible price. As the cupola can make iron considerably cheaper than the electric furnace, the latter is being more widely used where the quality of the metal far outweighs any slight increase in the cost of production. Such instances, as in the manufacture of castings to withstand high pressures or in cases where metal of absolute regularity of composition is desired, offer the most outstanding examples of the use of the electric furnace. Of course, under certain conditions the electric furnace is cheaper by being able to offer a stronger iron of thinner section such as in pipe work, etc., where this ratio is in favor of electric operation. In parts of the country where power is cheap, and coke and pig iron dear, for instance on the Pacific coast, the electric furnace is coming forward on its cost basis more than on its advantages of producing metal of higher quality.

#### *Melting Gray Iron by the Acid Process*

The acid process offers the qualities of superheating only. It has no powers of desulphurizing or deoxidizing by the use of certain slag baths, its power of eliminating the bases being strictly a function of its silicon. The regularity of composition may be considered as fair only, due to the rapid changes of silicon in the metal, especially at higher temperatures. It offers certain economic advantages of cheapness, and ability to use certain classes of scrap inapplicable to cupola melting. Its use is ex-

tremely limited and there seem to be no points which should warrant any great increase in its use.

Its main advantage lies in the fact that the shop making a specialty of steel castings has at hand the required equipment necessary to make iron castings as a fill-in job. This is important, especially in locations far from the base of supply where an iron casting is often required in a great hurry for a breakdown job. Then, the shop making both iron and steel castings in the electric furnace is enabled to offer more regular operations with the great advantage of a hot furnace and a lower-



Fig. 46—Note the Numerous Small Shrink Spots Caused by Pouring Iron Too Cold

ing of the overhead. That these points are appreciated is shown by the large number of foundries making steel castings, which also are engaged in the manufacture of iron castings as a side line.

For regular operations on iron the author cannot recommend the acid furnace, the basic process offering far greater advantages. This acid iron practice is given merely as a metallurgical aid to the shop which at any time may be called on for a heat of gray iron.

*Melting Down*

The furnace is charged in a manner similar to the practice in making a heat of steel, the charge consisting of a good grade of cast-iron scrap, with which may be mixed as many cast-iron borings or turnings as can be had. It must be remembered that a soft, high speed machinable iron, cannot be made in the electric furnace from any other class of scrap than that mentioned, with the one exception of pig iron, which is eliminated due to its prohibitive cost. Cases have been noted where soft, gray iron was made from a base of steel scrap, but the



Fig. 47—Fracture Test of Gray Iron Casting Made From Metal Melted in an Acid Furnace

author worked on this problem for nearly two years, and found that while it could be made with certain reservations, its use could not be recommended due to the lack of regularity.

As cast iron has not the conductive power of steel, trouble may be experienced in obtaining an arc at the start of the heat, especially if melting a charge of 100 per cent borings. This offers no difficulty as the electrodes may be lowered until they are resting on the charge. The current will immediately begin its passage

through the metal, and while there will be no heavy load pulled, the result will be innumerable small arcs breaking throughout the furnace. The result of this, together with the heat caused by resistance, will be the formation of small pools of metal throughout the charge and as these increase in size, the load will pick up, and the bath will come down rapidly. If no load at all can be drawn, a small amount of coke, or an old piece of electrode may be placed over the top of the charge to draw the arc. The flame soon will fuse the top layers of the iron enough to form contact and the arc will pick up rapidly.

#### *Carbon Loss Must Be Corrected*

As there will always be a slight loss in the carbon content on melting down, this must be counteracted by the addition of a small amount of coke added with the charge, 0.25 per cent carbon content being the average amount. This should be added about in the center of the charge so that it will be in the area of highest temperature, such a condition being favorable to maximum absorption.

As soon as the charge has melted, a metal test should be taken and poured in a sand mold. As soon as black this may be broken and judged by fracture or sent to the chemist for a carbon test. The fracture test is reliable, and while it does not denote the percentage of carbon, it does show whether the metal is soft enough for the average casting. If the carbon is of the proper percentage, the heat may be continued. If the fracture shows the heat is likely to be too hard, coke must be added and rabbled into the metal. Superheating the metal, and freedom from slag are the two main points to consider in raising the carbon content, a high temperature and low slag body favoring such action. The recarbonizer used should be of low ash content, and of sufficient weight so that it will not float too high on the surface

of the bath, as charcoal for instance will do. Graphite flakes are excellent for such a purpose, as is a good grade of low ash coke or anthracite coal, as low in sulphur as can be had.

This fracture test also will show relatively the silicon content. This may require a slight addition. In this respect we encounter a peculiarity in that the melting point of ferrosilicon is above that of the iron. This addition will float on the surface of the bath until its

Table XXXIX  
CHEMICAL CHANGES IN ACID CAST IRON

	Percentages of			Phos.	Sul.
	Tot. Car	Mang.	Sil.		
Borings 100 Per cent					
Charge . . . . .	3.44	0.63	2.12	0.244	0.077
	3.39	0.63	2.16	...	...
Heat analysis . . . .	3.39	0.66	2.13	0.248	0.077
	3.41	0.66	2.17	...	...
Pig iron 100 Per cent					
Charge . . . . .	3.47	0.45	3.28	0.112	0.047
Heat analysis . . . . .	3.56	0.46	3.14	0.114	0.058
Charge . . . . .	3.45	0.55	3.27	0.039	0.014
Heat analysis . . . . .	3.12		3.24	0.022	0.023
Charge . . . . .	3.75	0.51	3.26	0.042	0.010
Heat analysis . . . . .	3.69	0.55	3.12	0.042	0.024

character has so changed by fusion and combination with the iron itself, that its melting point, is lowered and absorption results. Therefore, it is imperative that no such addition should ever be made unless accompanied by sufficient carbon to assure a highly reducing atmosphere. The silicon need offer no difficulty as when the temperature of the iron becomes high, the slag may be slightly thickened when the silicon will be reduced into the metal from the silicon of the slag, in a similar manner to the action of a slag on a heat of acid steel, although not at all noticable, except by the appearance of the fracture or the analysis of the chemist.

As soon as possible the carbon should be adjusted, that the finishing slag may be built. Such a slag is



required to hold the heat in the metal and to prevent radiation to the refractories. This slag is made of sand mixed with lime, the lime consisting of 20 to 25 per cent of the mixture. Enough is used adequately to cover the metal. At first this slag may tend to lump, but as the temperature increases in the furnace, it gradually will melt, and by being rabbled occasionally will diffuse thoroughly and furnish the proper blanket condition.

Considerable manipulation is required to keep such a slag in its proper condition. Due to the high silicon content of the metal, this slag is likely to thicken to a point where it becomes thick and gummy. The antidote to such a state of affairs is either a little lime, or limerock, carefully spread over the surface. Marble chippings, and oyster shells may be used to furnish the lime content and give fine service at a low cost. The log of an acid electric furnace is given in Table 24, Appendix.

#### *Bring Up Temperature*

The analysis of the metal being satisfactory, and its fracture appearance good, the next step is bringing up to temperature. Tests are taken with a standard spoon until the metal begins to lose its sluggish appearance.

At this point, the iron rapidly is becoming superheated, and when it reaches a bluish appearance, it is hot enough to pour the most intricate castings. The heat is tapped and ordinary foundry procedure followed.

From this it may be seen that the melting of iron on the acid hearth is but a step in advance of cupola operations in that it allows of certain refinements, namely superheating and a slight adjustment of the chemical contents as given in Table XXXIX. Some physical tests are given in Tables XL and XLI.

The basic process offers the great advantages for

melting gray iron, in that superheating is possible, and there is the added advantage of great refining, coupled with close chemical control. It is toward this method of operation that future developments are tending along wider lines.

By using the cupola to melt the charges a large saving is made in the cost of conversion, as practically

Table XL  
PHYSICAL TESTS OF ACID IRON\*\*

	Tot C	Mang	Sil	Phos	Sul	Load	Mod. of Rupt	Deflection
Borings . .	3 21	0 50	2 46	0 58	0 098	3460	54000	0.154
	3 18	0 46	2 11	0 72	0 090	3220	50200	0 171
	3 26	0 57	2 29	0 51	0 088	3330	52000	0 183
Pig and scrap	3 25	0 74	2 18	0 10	0 025	4280	51200	0 175
	3 26	0 57	2 21	0 24	0 030	3370	52600	0 212
	3 28	0 76	2 20	0 24	0 044	3300	51500	0 157
Shop scrap	3 28	0 50	2 21	0 51	0 082	3610	56300	0 159
	3 30	0 50	2 15	0 52	0 087	3370	52500	0 195
	3 23	0 47	2 32	0 48	0 086	3420	53400	0 175

\*\*H M Williams and T B Terry, Trans Am Elec Chem Soc, May, 1922

Table XLI  
ACID ELECTRIC FURNACE IRON\*

	Tot C	Mang	Sil	Phos	Sul	Cl	Ni	Load	Mod of Rupt	Defl
Pig Iron, shop scrap and 20 per cent steel										
3 24	0 60	2 13	0 58	0 065				4440	69250	0 185
2 97	0 57	2 10	0 54	0 069				4680	73000	0 175
3 24	0 76	2 47	0 69	0 025				4250	66300	0 222
3 16	0 70	2 45	0 155	0 024				4350	67900	0 200
3 01	0 50	2 00	0 138	0 026				4680	73100	0 183
Pig Iron, 20 per cent steel 10 to 12 per cent Mayan Iron										
3 07	0 70	2 62	0 22	0 037	0 40	0 20		4480	69800	0 169
3 11	0 58	2 69	0 248	0 038	0 36	0 18		4520	70500	0 172
3 02	0 65	2 72	0 12	0 030	0 25	0 12		4570	71400	0 175
3 31	0 68	2 28	0 120	0 025	0 30	0 15		4460	69500	0 230
3 03	0 56	2 58	0 085	0 023	0 28	0 14		4640	72300	0 241

\*H M Williams and T B Terry

80 per cent of the power used is for melting. The advantages of the electric furnace, except in special cases, are manifested only during the finishing operation, after the heat has reached the molten state. Any means to cheapen or hasten the melting of cold scrap is of prime importance and deserves serious consideration.

The metal as melted in the cupola does not require much pig, only enough being used to insure proper melt-

ing, and in many cases a charge of 100 per cent scrap may be used. This molten metal is transferred to the electric furnace by an ordinary foundry ladle, and as soon as it is placed in the furnace, the current is turned on, the lime slag added, and the metal superheated and refined to the desired point. Improvement in the iron by using the duplexing process is given in Table XLII and the log of a duplexed heat in the Appendix. Table

TABLE XLII  
IMPROVEMENT OF CAST IRON DUE TO DUPLEXING<sup>1</sup>

	Carbon	Silicon	Manganese	Phosphorus	Sulphur	Transverse strength
Cupola	3.48	1.92	0.56	0.53	0.099	2812
Electric	3.38	1.82	0.61	0.51	0.022	4118
Cupola	3.50	1.79	0.54	0.62	0.158	2770
Electric	3.22(1)	1.94(2)	0.54	0.61	0.052	3985
Cupola	3.35	1.91	0.72	0.59	0.091	3748
Electric	3.26	1.77	0.73	0.58	0.018	5096
Cupola	3.40	1.94	0.42	0.58	0.069	3602
Electric	3.41	2.21(2)	0.44	0.56	0.026	4212
Cupola	2.90	1.51	0.43	0.51	0.151	
Electric	2.91	2.28(2)	0.51(3)	0.55	0.013	4200
Cupola	2.77	0.89	0.24	0.44	0.160	
Electric	2.69	2.18(2)	0.52(3)	0.40	0.057	5114
Cupola	3.39	2.16	0.77	0.62	0.057	2815
Electric	3.14(1)	1.90	0.81	0.55(4)	0.019	2824
Cupola	3.45	1.83	0.34	0.48	0.112	3316
Electric	3.38	2.30(2)	0.36	0.17	0.033	4022
Electric only	2.94	1.52	0.62	0.27	0.009	4144

(1) Carbon reduced by mill scale in electric furnace

(2) Ferrosilicon added in electric furnace

(3) Ferromanganese added in electric furnace

(4) Carbon and phosphorus reduced by dilution with steel

\*G. K. Elliot

25. While this treatment greatly improves the iron it involves a certain cost. Consequently, the best success is obtained when the cupola itself is operated along lines of the highest possible efficiency. Iron which has been badly burned in the cupola, or iron from a poor grade of scrap, never can be brought back into a first class metal, except at an unreasonable cost in time and current for electric refining. In the same manner, the hotter the iron comes from the cupola the less time required in the electric furnace to superheat. Hot cupola metal means a considerable power saving.

The time which will be required for a heat of iron

to be duplexed in the electric furnace will depend upon certain points. These are:

The sulphur in the initial charge.

The sulphur allowable in the final product.

The initial temperature of the iron entering the electric furnace.

The required pouring temperature.

The condition of the metal in relation to its amount of oxides or other gases which must be eliminated.

The amount of chemical manipulation which may be required.

### *Removal of Sulphur*

Under a lime and fluorspar slag, consisting of approximately 2 per cent of the charge in weight, it will take about 30 minutes under a white falling slag to lower the sulphur 0.05 per cent. The same length of time will raise the temperature of the iron poured into the electric furnace about 275 to 300 degrees Fahr. As conditions change, this period may be prolonged to an hour, or even more in special instances. For the shop entering on electric duplexed iron, 45 minutes will prove to be suitable at the start, until exact figures are obtained, when the time may be either lowered or increased.

George K. Elliott, Lunkenheimer Co., Cincinnati, gives the following figures on the elimination of sulphur during duplexing:

Per cent sulphur	Time in electric furnace minutes
0.156	As received from the cupola
0.133	10
0.112	20
0.079	30
0.036	40
0.031	50
0.014	64

From these data it may be seen that this particular heat could have been nicely poured at the end of the 40-minute period, the melting in this instance being prolonged in order that further data on the sulphur reduction could be obtained. The refining action of slag on a

heat of cast iron is extremely powerful, due to the fact that the slag may be literally soaked with coke dust or other carbonaceous matter, without any detriment to the metal, a point of impossibility when working a heat of steel. As the elimination of sulphur follows directly the rise in temperature, a high temperature coupled with a heavy carbide slag is a strong indication of the degree of desulphurization. Of course, exact figures of time must be worked out accurately for each shop, as different localities will have scrap, varying in its condition and also in its chemical analysis.

#### *Adding the Slag Forming Material*

Assuming that the electric furnace has just finished pouring a heat of either iron or steel, the first step will be the patching of the hearth and walls, and the time allowed for this fettled material to set slightly. The furnace now is ready for the ladle of metal from the cupola. Several permissible methods of adding the slag making material may be followed. It may be added on the hearth before the ladle is brought up; it may be added to the furnace as the metal is being added; or it may be added after the furnace has been filled.

Of these three the second method probably is the best. If the slag making material is added to the hearth, there is always a tendency for the lime to cake and build up the bottom, requiring added labor to keep the hearth in its proper shape and depth. If the slag making material is added to the iron after the furnace has been filled, there is again the tendency to cake until the iron has become thoroughly superheated, thus lessening the effective time in which this slag has to operate on the metal. By adding the slag material to the incoming stream it is at once heated throughout; it is thoroughly distributed not only on the surface of the metal, but throughout the mass of the iron itself. Therefore, there

is little chance of this slag caking, and the effective time of refining is lengthened.

This slag will be made of the required amount of lime thoroughly mixed with crushed fluorspar and coke dust. The spar will consist of about 20 to 40 per cent of the lime, while the coke will be the amount required to give the slag mixture a dark color. This slag either may be shoveled into the furnace or placed in a chute over the door so that by opening a door the contents will flow into the stream, in a manner similar to certain open hearth installations where such a contrivance is used to add the ferroalloy to the ladle. The main points of importance relative to the slag are that it should be of a small mesh size, and that it should be thoroughly mixed. The easiest method of obtaining such conditions is to mix a large batch at one time in a grinding pan, where the components are not only thoroughly mixed, but pulverized during the operation. While the data on slags are followed by the author, changes may be required in various localities, due to changes in the scrap available, the character of the lime and spar, etc.

### *The First Operation*

The metal and slag being in the furnace the entire bath is given a heavy dusting of coke and the furnace sealed. If working under strict chemical specification this is the proper time to take a test for chemical examination. Otherwise the furnace doors are tightly closed and the current started. It will take approximately 10 minutes under a full load to eliminate the chilling effect which the metal has experienced during transportation from the cupola, unless the iron has been tapped at a high temperature. At the end of this 10 minutes, the door should be opened and the slag examined. If of a satisfactory carbide character, a metal test may be taken for temperature and fracture appearance. If the slag

has lumped, which is often the case, it must be rabbled thoroughly to break up the cakes, and may even require more spar. If too thin, more lime should be added. As slags on iron are under a lower temperature than on steel, this caking effect is more pronounced and it may require considerable experimenting until all additions are in proper condition. If the slag cakes, the only method of breaking it is by rabbling, and by the addition of either spar or sand. Sand should not be used, unless it is shown that the amount of spar being added is detrimental to the hearth and walls, as any undue percentage of silica in the slag will be reduced under such powerful carbide conditions, often resulting in a wide variance of the silicon content of the finished metal.

### *The Second Operation*

As soon as the slag is of the proper consistency, a test should be taken to determine the degree of reduction which is present in the furnace. This is made by taking a sample of the slag, pouring part on an iron plate, and cooling the remainder in water. If the slag is correctly proportioned, that poured on the plate will begin to crumble and fall apart as soon as the test becomes black. The surface of this slag either will be black or chocolate brown, the interior powder being dark gray. The slag will act as if worms were inside it, the best illustration being the way the ground appears when a gopher is coming to the surface. The test cooled in the water will be grayish slush giving off a heavy odor of acetylene. While this is the customary appearance, the author has observed cases where the slag was hard and tough, of a reddish brown appearance yet contained nearly 10 per cent of calcium carbide. Such a slag is of rare occurrence, yet is far more powerful in its reducing action than the ordinary carbide, powdering slags.

Conditions are now right and the metal should be

held in this manner only long enough to insure the lowering of the sulphur to the required point. Superheating will be coincident with this desulphurization, and as this latter generally takes longer, unless on iron intended for large sized castings, is generally used as the furnace indication. Metal tests are taken in the ordinary manner and poured into a sand mold, the best size being a 1-inch square bar, 6 inches long, cast on end. From the appearance of the metal as it pours over the lip of the spoon, and from the appearance of the fracture of this test piece, the temperature and quality of the metal are judged. As soon as the metal has a soft appearing fracture, coupled with the bluish color when pouring, the metal is in proper condition to tap. On heats of iron which are extremely hot, the metal when poured will be accompanied by short blue flames shooting from the stream, exactly the same as on a hot steel heat.

### *Alloy Additions*

The required additions of alloys should be made as soon as a fair temperature is attained so that any of the constituents entering the slag may be reduced into the metal, and diffused before the furnace is tapped.

Such a heat will be accompanied into the ladle by this basic slag which is difficult to handle. It is so fluid that any attempt to skim while pouring is futile. Lime added will thicken the slag on the surface but a considerable quantity of the slag will remain under the surface. This slag will run into the mold if any attempt is made to pour it in this state. Incidentally, this additional amount of lime will prove to be rather expensive. There are three main solutions to this problem. These are the use of a bottom pour ladle; the use of a tea spout ladle; or pouring from the furnace ladle into another, keeping the greater portion of the slag in the former. During the pouring, the small amount of slag which remains with



the metal may be skimmed. The choice of these methods will depend upon the opinions of the supervisory forces in the various foundries, and needs no discussion at this time.

### *Using Cold Stock*

Highest grade electric iron castings are made by melting cold stock on a basic hearth due mainly to the following reasons:

The metal may be more carefully charged according to class of scrap and analysis of metal.

The metal does not oxidize or burn during the melting down operation, requiring any bringing back.

The heat from the start is under a strong carbide slag allowing a greater period of refining.

For the highest grades of casting it is natural that the best possible grades of scrap should be used, and pig iron occasionally is charged for special heats. As the amount of machining to be done on the casting decreases, the cost of the heat is lowered by the use of steel. Thus by manipulating the charges of irons, varying compositions may be made from the softest, open-grain iron to that close-grained, hard iron containing 100 per cent steel charge.

The furnace operation is no different from that followed in the duplexing process, except that the slag mixture is added with the charge. A small amount of coke always is added to insure proper reducing conditions, and to take care of any slight amount of carbon which may be oxidized by the rust of the charge. Alloy additions, when necessary, are added near the end of the heat when the metal has been superheated sufficiently to insure proper diffusion. Heat logs on cold stock and iron borings are given in Table 26, and 27, Appendix.

### *Synthetic Gray Irons*

Synthetic cast iron, or iron made from a steel scrap base, found considerable use during the war. The use of

such iron was founded upon sound economic reasons, caused in the main by prohibitive prices for cast iron scrap. With steel borings at such low prices as \$5 to \$8 a ton as against \$40 to \$45 for cast scrap, it was found that the cost of manufacturing synthetic iron in the electric furnace was considerably cheaper than the cost of producing cupola metal.

With war conditions over, further experiments were made on this synthetic iron to overcome certain difficulties in its manufacture. Synthetic iron as made in the electric furnace has properties differing widely from the ordinary cupola metal. Some of these are more favorable, while others are distinctly derogatory. Synthetic iron, and its properties may be briefly summarized.

Due to the uncertainties of its manufacture, this iron cannot be controlled closely in its physical structure. Consequently, one heat is likely to be exceedingly soft, while that following offers considerable difficulty to machining at high speeds. The result of this, is that synthetic iron finds small use for the better grades of machineable castings, where a uniform softness is desired. Its widest use is in those instances where a harder, yet machineable iron is required.

### *Properties of Synthetic Iron*

While synthetic irons cannot be machined at high speeds, they may be drilled easily, and find extensive use in such instances as the general run of car castings, where little machining is done.

Such irons contain unusually low percentages of phosphorus and sulphur. Consequently, they are much stronger and tougher than the high phosphorus cupola metal, which is a distinct advantage for certain classifications.

Synthetic irons are close grained, which is a distinct advantage especially on pressure castings. The silicons

may be controlled closely, making easy the manufacture of irons of varying hardness.

In general such metal offers great advantages to any foundry and the natural result is that its use is rapidly increasing. In the manufacture of this metal but one point of difficulty is encountered. This is the care required to obtain a suitable carbon content. When a heat of steel scrap is melted in conjunction with an excess of coke it would appear on the surface that the absorption of this carbon, in the presence of the large amount of superheated iron should be rapid. Yet, when the actual heat is made, it is found that such is not the case. Operating under ordinary conditions, such a heat will melt down at about 2.50 to 2.75 per cent carbon, regardless of the amount of coke present in the furnace. If the heat is held at high temperatures for a considerable length of time, this carbon gradually will rise until close to a figure of approximately 4.00 per cent above which the carbon cannot go, except at extremely high temperatures, held for long periods.

#### *Economic Methods of Increasing Carbon*

As cast irons to be in any degree soft, and readily machineable, should have carbon contents from 3.25 to 3.75 per cent, it may be seen that bringing the carbon content up these few extra points is the seat of difficulty. As the absorption of this extra carbon must also be an economic proposition further obstacles are encountered. With this idea in view of determining methods of quickly and cheaply raising the carbon content, many experiments have been made.

The bureau of mines in Seattle, Wash., the author in Los Angeles, Calif., W. L. Morrison in Seattle, and many others both in this country and abroad have worked on this proposition, independently, but following the same

general trend, and with practically the same results. Briefly enumerated the results obtained are as follows:

Regardless of the amount, or the class of the recarburizer used it is seldom that the iron will, on the melt down, contain more than 2.75 per cent total carbon.

A low ash recarburizer is more effective in further raising this carbon than one of a higher ash content.

Recarburizers which are heavy, and sink low in the metal, such as graphite and petroleum coke, are more ef-

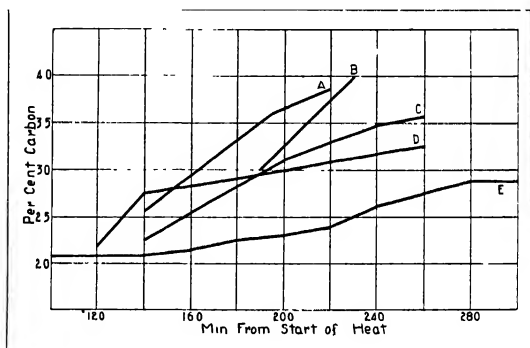


Fig. 48—Various Recarburizers Affect a Heat of Metal in Different Ways. The Curves Show the Effect of: A, Coal Tar Coke; B, Flake Graphite; C, 13 Per Cent Ash Coke; D, Charcoal; E, 25 Per Cent Ash Coke

fective than those which float high on the bath such as charcoal or porous coke.

Time and temperature are two main points determining the amount of carbon absorption.

Slag on the metal greatly lowers the amount of absorption in a given length of time.

Rabbling the metal is a great aid in the rapid pick up of carbon.

An acid slag holds back the absorption more than does a basic carbide slag.

Silicon has no effect on the carbon absorption; man-

ganese seems to aid this process; sulphur retards the pick up; phosphorus is negative in its action.

Figs. 48, 49, 50, 51, 52 and 53 show graphically the result of the above findings. These are taken from report of the work done at the Seattle station, bureau of mines, by Clyde E. Williams, and C. E. Sims.

While the majority of the experiments made on synthetic iron were made in open top furnaces with electric furnace pig iron in view, those of the author were made

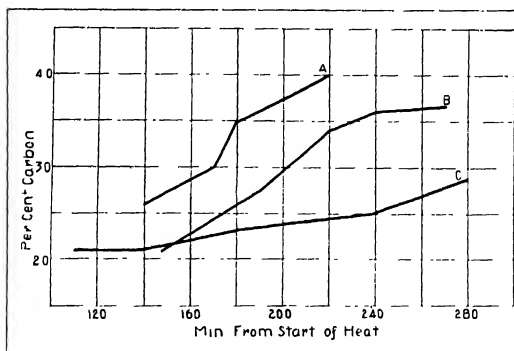


Fig. 49—The Effect of Ash in the Recarburizers is to Govern the Speed of Absorption, as is Shown by: A, Coal Tar Coke Less than 4 Per Cent Ash; B, Low Ash Coke, Ash Content 12 Per Cent; C, Coke, 25 Per Cent Ash

in standard arc furnaces, the metal being poured directly into iron castings. However, results are similar on the two processes, although the pit, or open-top furnace gives better carbon absorption. As the metal from such a furnace is not uniform its use in the foundry would not be practical unless accompanied by an auxiliary melting unit.

Any grade of steel scrap is suitable for synthetic iron, the cheaper in price the better with the one exception that

such low grades of metal as baled tin cans, or burned iron will not be cheap at any price. The author worked for some length of time with the former and was unable to obtain satisfactory results under any conditions.

### *Starting the Heat*

In starting a heat, charge on the hearth of the furnace the carburizing material calculated to 3.50 per cent carbon, the efficiency, determined by the material used,

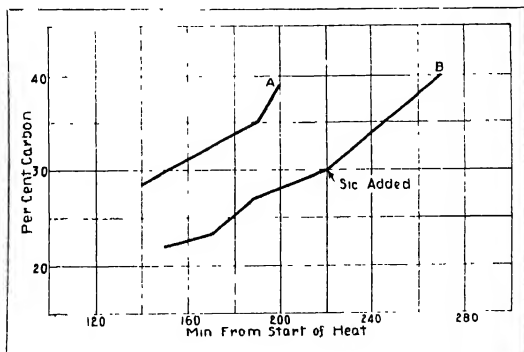


Fig. 50—Effect of Using Natural Silicon Carbide, Carborundum, After the Bath is Melted is Shown as Follows: A, Heat, Run With Coal Tar Coke, a Highly Efficient Recarburizer; B, Coke With 25 Per Cent Ash Used to Point Where Carborundum Sand Was Added

ranging from 50 per cent for common coke to 75 per cent for graphite, based upon the carbon content. The material should be of small mesh preferably under  $\frac{1}{8}$  inch in size. Under no conditions use any slag material. Now charge the metal and turn on the current, sealing the furnace as far as possible, as any air entering the furnace will result in a needless burning up of carbon. As soon as small pools of molten metal form under the electrodes,

throw a small amount of the recarburizer in these holes. This will tend to steady the arc, and at the same time will furnish a spot of carbon directly where needed. This will increase the speed of melting as, during the heating of the metal to its melting point, it will absorb carbon slightly and aid by a lowering of its fusing point. Be sure that the doors are kept sealed at all times.

As soon as the bath is melted, open the doors and inspect the furnace. Any material on the walls may be

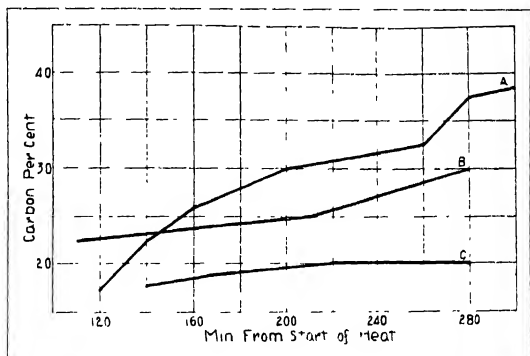


Fig. 51—Slags Exert an Effect in Retarding Absorption: A, High Ash Coke With Carbide Slag; B, High Ash Coke in Presence of Acid Slag; C, High Ash Coke on Bare Metal, Explained by Elimination of Coke Carbon Picked up by Entering Air From Doors

pushed in and the surface of the metal may be inspected for any slag coming up from either the hearth or the scrap charged, usually consisting of the dirt and impurities held with the charged metal. If any slag shows, it should be raked off carefully and sufficient of the recarburizer added adequately to cover the molten metal. Next, take a spoon test and pour into a sand mold on end, a bar about 1 inch square and 6 inches long being a satisfactory size. Leave

this bar in the sand until it is black and then air cool or water quench. This test, on fracture usually will show blowy and will be clear white. The crystals will appear rather fine, but the structure will be irregular and more or less feathered, the exact outline of the crystalline structure being indistinct.

#### *Further Additions Unnecessary*

If a chemist is at hand a sample may be sent for an analysis of the carbon, which in the vast majority of cases

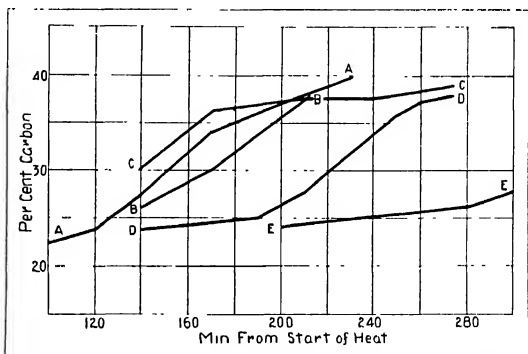


Fig. 52—Various Elements Affect Carbon Absorption: A, Manganese Content of Metal, 1.75 Per Cent; B, Silicon, 2 Per Cent, Other Alloys Low; C, Practically Pure Iron with Silicon, 0.20 Per Cent, Manganese, 0.40 Per Cent, Sulphur and Phosphorus, 0.05 Per Cent; D, Phosphorus, 0.70 Per Cent; E, Sulphur, 0.75 Per Cent

will show from 2.50 to 2.75 per cent. If there is plenty of the carbon on the metal, it will not be necessary to make any further additions, if not, enough must be added to cover the iron. It is important at all times to keep the bath of molten metal covered thoroughly with an excess supply of the recarburizer until the percentage of carbon is at the desired point.



If the metal is hot enough to run cleanly from the test spoon the next step may be taken; if not, the bath must be heated further. When a superheated temperature is attained, the bath may be boiled to raise the carbon.

Several shovels of graphite flakes or carborundum sand should be thrown in and green wood poles inserted through each door. These poles should be about two inches in diameter and as long as it is possible to obtain. They are inserted into the metal about a foot deep and

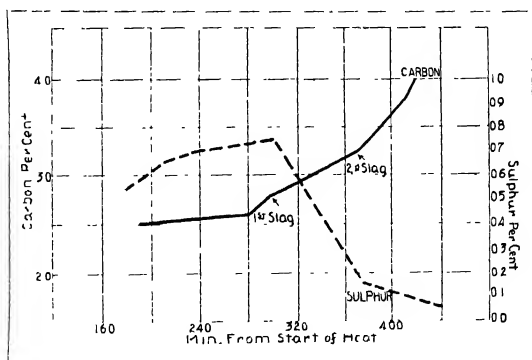


Fig. 53—The Rate of Carbon Absorption is Increased at a Rapid Rate as the Percentage of Sulphur is Lowered, in This Case by Two Carbide Slags; A, Percentage of Carbon in the Metal as Heat Advances; B, Curve of Sulphur Content Showing Effect of Slags

moved from side to side, the current being turned off. A violent boiling will ensue, the recarburizer will be mixed throughout the bath, and the carbon will rise rapidly. Boiling in this manner for 15 minutes with two poles easily will raise the carbon content from 0.40 to 0.50 per cent. After the first boiling period of about 10 minutes, the current again is turned on and another metal test taken. This process should be repeated until two tests

are obtained approximately of the same fracture appearance. This denotes that the molten metal is nearing equilibrium under the given conditions.

Such a metal, if the temperature is high, should contain from 3.25 to 3.50 per cent carbon. The test will show a *fiery* fracture of large size crystals radiating from the center. The metal will have a close knit appearance, and will show freedom from blowholes or flaws. The general color will be a deep white tending toward a grayish color, the crystals appearing clear cut and distinct. The ordinary lime slag now may be added, together with the alloys, and the final period begins.

#### *May Judge by Fractures*

As soon as the silicon enters the metal the appearance of the iron changes. It assumes the sluggish flow of ordinary gray iron, but has a bluish color, and a sparkling flow much different from the ordinary grades of cast iron, due probably to the low percentage of phosphorus and sulphur. The metal now may be judged by fracture and when the softness has reached a maximum the iron can be tapped.

#### *Neutral Hearth Melting*

Experiments have been conducted on melting iron on a neutral hearth, the idea being that either acid or basic operation could be affected in the one furnace. Irons of low sulphur could be melted under acid conditions, while those with a higher percentage of this element could be refined under the ordinary lime slag. The lining materials used in making the neutral hearths were mainly two, chrome ore and rammed carbon.

The chrome ore offered such difficulty in obtaining a well sintered and lasting hearth that its use quickly was discarded. The carbon hearth gave better results, but they were not such as to promise any advantages over the

ordinary methods of melting. While it was found that the metal did pick up a little carbon from the hearth it was insignificant, the greatest trouble being the rapid wearing away of the banks and jambs. This was pronounced, especially above the metal line, where any entering air directly impinged and combined with the carbon of the walls. A set of jambs would not wear any length of time and these operations quickly were discontinued.

For the shop making nothing but gray iron, the carbon hearth offers certain advantages, especially in the absolute freedom of any included gases coming from dissolved oxide, and with the higher quality of refractories which at present can be obtained, this process might be so developed as to give favorable results. The amount of time which the author spent on this process was limited and his results cannot be accepted in any manner as final or absolutely authoritative.

### *Controlling Characteristics*

Synthetic gray irons are peculiar in their actions. Two heats of practically the same analysis, made from the same scrap, and melted under exactly the same conditions will have widely differing qualities. One will be as soft and free cutting as any iron could be, while the next may be so hard that it can be drilled only with difficulty. Naturally, in the shop producing castings from this metal such conditions could not exist as there would be an endless amount of trouble from mixing the soft and hard irons.

This is the situation which first confronted the author when experiments were being conducted on this metal. It was obvious that the differences occurring in irons of similar analyses only could be caused by differences in structure on cooling, and experiments were conducted along lines of different treatments to give a uniform soft-

ness to castings produced by this method. It was found that the hard irons quickly reacted to a simple heat treatment, the metal being soft on cooling.

### *Heat Treatment*

The castings are charged into a cold or slightly warm furnace, heated by any of the ordinary methods, although the electric anneal is superior for regular results. Care must be exercised to support the pieces to prevent any tendency to warp and charging must be such that the entire charge is exposed directly to the heat. A small amount of some carbonaceous material is charged in the furnace to supply a heavy reducing atmosphere. If this is neglected the outer skin of the castings will be hard and offer considerable trouble when being machined. Heat the entire charge slowly to a distinct red color, the temperature at which maximum softness is obtained being close to 1400 degrees Fahr. Permit the castings to soak at this temperature until the heat is uniform throughout the various sections, when the furnace may be shut down, and the charge cooled slowly.

### *Strength of Metal Drops*

Castings annealed by this method show a soft iron, but that there is a considerable drop in the strength of the metal when so treated. Consequently, iron intended to meet a certain strength requirement cannot be handled this way. The usual test on a heat of synthetic iron is to cast a test bar 2 inches in diameter and about a foot long. When cold, after being allowed to stand in the mold until black, it is placed in a lathe and threads are cut in it. If it machines easily no further treatment is required on that heat.

While these experiments were being conducted, it also was found that this treating could be manipulated to obtain irons of different degrees of hardness from the

same heat. This was done by regulating the speed of cooling. A casting heated to 1400 degrees Fahr. and slowly cooled would be extremely soft, while one pulled from the annealing furnace and air cooled would be an unusually hard gray, often verging on the white. Also, it was found that castings could be made with one face hard, and the back soft and strong, by the proper use of chills, mud, lime, etc. This led to favorable results as almost any kind of an iron could be poured from the same heat, merely by changing the treatment. Chilled irons could be made without the use of a chill. This would constitute a great saving, especially where only one or two pieces had to be made in a hurry, with no time to cast a chill. With the many helps for the heat treating department which have been lately developed there is no doubt but that results of a surprising nature may be obtained by variations of the processes mentioned.

## XIV

### WHITE CAST IRON AND THE USE OF ALLOYS

**W**HITE irons have as their main characteristic a high degree of hardness. This qualification fits them for their greatest use, which is for parts subject to great abrasion, as in grinding and pulverizing of ores and miscellaneous minerals. The ordinary grade of white iron, as made in the cupola, offers considerable difficulty to the foundryman if a high quality product is desired.

This metal has a much higher freezing point than has ordinary gray iron, with the result that a ladle of white iron must be handled quickly if it is to be poured free of heavy skulls. Consequently, the cupola is forced heavily to melt this iron at the highest possible temperature, and quite often a large amount of the iron must be pigged, being too cold to pour.

In view of the foregoing, it is natural that many castings are poured with iron practically at the freezing point. The evident result is castings full of defects, caused by the inability of both gaseous and solid inclusions to free themselves before the iron sets in the mold. For these reasons the average foundryman will tell you at much length of the difficulty of handling this metal, and will offer such facts as the high melting point of the iron, its tendency to crack in the mold, its troublesome frequency of blowholes, shrinkholes, draws, and seams, in proof of his contentions.

While it is true that white iron from the cupola offers much difficulty, the exact opposite is true of that class of metal as melted in the electric furnace. The electric furnace will superheat to any temperature and for this reason the iron may be made so hot that any class of castings can be poured with ease. Castings poured from

electric furnace white iron are practically free from those defects caused by cold metal, which in hard iron constitutes the greatest reason for lost castings. When to this great advantage the ability to refine and keep to regular analyses is added the electric furnace easily proves its superiority. Of late years, the use of alloys, in these irons intended as a resistant to abrasive action, steadily has increased. Here again the electric furnace offers the economical and important characteristic of being able to reclaim a large percentage of the high priced metals.

The author for a considerable length of time was engaged upon the development of a special class of white iron, intended for use under the heaviest kind of service, where resistance to abrasion was desired, and where the metal resisted shock to a marked degree. From these experiences a considerable amount of important and interesting data was obtained upon the manner in which such irons reacted to melting, both in the cupola and in the electric furnace. From these observations, the writer has no hesitancy in stating that white iron, as made in the electric furnace under good metallurgical practice, offers superior qualities to anything on the market for abrasive purposes, except it be manganese steel, and in certain instances when the cost factor is considered—is ahead of this alloy steel.

For those who are not thoroughly familiar with the operation of various grinding equipment the writer will give a short resume that the desired properties of such an iron may be brought to light.

*Class 1—Operations where only resistance to abrasion is desired.*

One of the outstanding examples of such work is the mixer blade, or paddle, used in forming the center of a concrete pipe. This class of pipe largely is used along the Pacific coast for irrigation work, being made in sizes from 8 inches in diameter up to about 36 inches. A form is

made, the inside diameter of which is the same as the intended outside diameter of the pipe. A central shaft, which may be raised and lowered, has several paddles attached of such a size that their path or rotation is the circle forming the inside diameter of the pipe. A batch of concrete is mixed and poured in a rather thick and pasty condition into this outside form. The blade shaft then is rotated and lowered into the concrete, the force of the blades pushing the mixture to one side, and forming the shape of the pipe. As the concrete sets the shaft is raised until a complete length of pipe is formed, when the machine is stopped, the pipe removed, and the operation again repeated.

This concrete offers terrific abrasion against the paddles, and also the outer shell. As the shell wears away, larger blades may be used until the tolerance is too great, when another shell must be placed in operation. This also is true of the blades which wear away extremely fast.

Similar examples are met with in certain pulverizing operations where the iron is used in the form of rollers, shells, etc., the material being pulverized ranging from common bricks to ordinary lime for building purposes.

*Class 2—Where a certain resistance to shock must be had in addition to the abrasive resistant properties.*

The most common example of this is in the ordinary ball mill, used principally for grinding ores, miscellaneous minerals, and cements. White iron castings find use in these ball mills under two main headings, as the balls, and as liners. A ball mill is a large cylindrical machine arranged to rotate on its axis in a horizontal direction. The outer shell of the machine usually is constructed of heavy steel plate, so arranged that the cast liners fit against it to form an inner lining of from 2 to 4 inches thick, depending on the make and size of the mill. A large



number of cast iron balls and a certain amount of ore are charged into this mill. The mill then is started revolving, the movement of the balls grinding, and then pulverizing the ore. The mill is arranged with screens of the desired mesh so that as the ore is pulverized it passes out these screens, its place being taken by fresh ore.

A ball mill is operated to produce fine material on a tonnage basis and anything which means a shutdown rigorously is avoided. Shutdowns are caused by two main reasons, the failure of a liner, or by the balls breaking up so fast that they clog the mill's output, when the machine must be stopped until these ball fragments can be removed. When it is considered that some of these mills have a lining weighing 35,000 pounds, with a ball charge of 68,000 pounds, it is easy to see that the movement of such a body of metal, with the added ore charge, offers a severe wearing action. Often a load will clog slightly allowing the charge to ride up on one side before slipping, when the entire contents of the mill is thrown heavily against the bottom. Under such conditions of service, a high quality iron is needed.

The common cupola grades of white iron at the period of the author's research, had proven so poor that the leading operators of ball mills had lost faith in such castings. Manganese steel was widely used for the liners, while forged balls of chrome steel were finding a ready market. There were several points derogatory to these metals. The manganese steel under the heavy peening action of the balls, tended to flow together at the joints with such force that a perfect weld often was made. When it became necessary to repair one part of the mill, considerable time was expended to tear these welded plate loose from one another, the cutting torch often having to be called in. With the steel balls, it was found that the wear was excessive, and due to the heavy freight

rate, they came from New Jersey and were used in the Pacific states, their cost was too high for economical operation. However, these metals were reliable in that there was no possibility of a break-down on the first few hours run, as was often the case with white iron.

*Class 3—Where the product offers heavy abrasion and at the same time must not be contaminated with pieces of broken material.*

This feature is desired in one of the industries using probably the greatest tonnage of white iron parts cast, that of cement making. The cement rock is pulverized in the ball mill pulverizers before, and after being burned. With a heavy breakage of balls, this raw cement is contaminated badly with particles of iron, the result being that the latter, when the cement is laid the iron comes to light as heavy rust streaks, often resulting in the rejection of completed work, due to the bad appearance of these rust patches. This was true especially of work exposed as in large buildings and sidewalks, where the reddish streaks made the work unsightly.

Consequently, for cement mill work, a metal was desired with a high degree of resistance to abrasion, and one which at the same time would not break or flake off in service.

From the foregoing, it can be seen that the uses and required characteristics of a first class white iron are about as follows:

The iron must be hard to resist abrasion.

It must be strong and tough enough to withstand a certain amount of shock.

It must have the ability to wear down without flaking or spalling.

Consequently, the manufacture of an iron with the required qualifications involves the best both of metallurgical and foundry practice if results are to be the best.

Before the electric furnace was used in melting white

iron, the cupola had been used on this metal for some time. An examination quickly disclosed that the arrangement of this cupola was such that its further use would only result in more trouble. The percentage of castings which were being brought back was enormous, and losses in the shop were out of all reason. To check the more common troubles, the returned and lost castings were segregated according to their various defects. It was found that practically all of the defective castings could be placed among the following classifications:

Blowholes, large size.

Small pin holes, under the surface skin of the casting.

Large interior shrink cavities.

Slag inclusions.

Sand spots.

Misruns, wrinkles, and seams.

Microscopic cracks, pits and tears.

Brittle iron and cracked castings.

Swelled or warped castings.

It was plain to see that the majority of these troubles were due to the pouring of the metal in a cold condition, and the electric furnace was brought into play. The first operations were conducted on the acid hearth.

#### *Acid Practice on White Irons*

Low silicon irons being extremely scarce, steel scrap, together with a certain amount of returned white iron, were used for the charge on white iron made in an acid lined furnace. Steel borings being rather cheap, in proportion to other classes of scrap, were used in large proportions. The practice was to charge enough scrap to cover the hearth thoroughly, then to charge the re-carburizer, figured at 3.50 per cent carbon, the effectiveness of the carbonaceous material being taken into account. As soon as the bath was melted, a test was taken to determine the carbon content of the metal. If

this was slow, the metal was boiled vigorously by using green wood poles.

Lower carbons were desired than is common in gray iron, a figure between 3.00 and 3.25 per cent carbon being considered ample for this class of work. Such a percentage was boiling under a heavy blanket of the recarburizer. Several varieties of carbonaceous material were used for this purpose, such as common coke of different sizes, low ash anthracite coal, and retort coke. All of them proved to give satisfactory results, the cheapest probably being the pitch or retort coke, which when ground to a wheat size raised the carbon quicker than any of the others.

#### *Slag Composition and Addition*

When the carbon content of the metal was correct, enough of a slag mixture was added to form a blanket for the bath, sufficient being added to prevent any surface oxidation and to prevent useless radiation of heat. This slag was tried of various percentages of sand, lime, and fluorspar, the mixture giving superior results consisting of about 20 per cent lime, and 10 per cent fluorspar.

As soon as the metal was approximately correct in chemical composition and the temperature was fairly high, the required alloys were added and the heat tapped as soon as these additions had time to mix thoroughly. After a considerable number of heats had been made in this manner, the operations were checked with the following conclusions:

Excellent temperatures of the metal were obtained, absolutely eliminating defectives from cold metal causes. The percentage of work lost by misruns, laps, seams, wrinkles, and coldshuts was cut down to a negligible figure. Blowholes, skin holes, and shrink cavities disappeared immediately.

Carbons were raised easily to the desired point, if proper precautions were observed, but considerable manipulation was required, caused by the carbon having a slight tendency to drop toward the end of the heat, especially when a high pouring temperature was used.

Phosphorus and sulphur content were extremely low, and the strength and toughness of the metal was much above that of the corresponding metal as cast from the cupola.

Silicon gave considerable trouble to secure proper regulation, especially on hot heats, where the slag thickened, reducing silica and often resulting in a silicon too high, giving a mottled heat, which proved too soft for the intended use.

Due to the large amount of coke in intimate contact at high temperatures with the silica hearth, a rather heavy erosion of the bottom and side walls was evident, requiring considerable patching and repairing in general.

The castings were subject to cracking, especially in the sand and considerable work was required on every heat to loosen heads, lighten cores, etc.

Due to the lower temperatures of the iron compared with those required for steel some difficulty was encountered in manipulating the slags properly to obtain correct finishing conditions. By taking plenty of time and by the use of larger amounts of lime, and fluorspar, these obstacles were overcome.

### *Results of Acid Process*

The results on acid operation were good, when considered in the light of the iron from the cupola. However, two main objections to this process were noted. These were the poor control of silicon and the tendency of the castings to prove tender in the sand. While these difficulties were common with the cupola metal, it was considered that iron made under the conditions of the

electric furnace should not show the brittleness it did. It was thought that the silicon control could be improved. A better class of steel scrap was tried, but the results were similar in every respect. Other changes in the melting practice, especially the temperatures of pouring, etc., were tried, but all methods gave results of about the same character. The hardest problem in this practice was the control of the analyses when melting returned shop scrap, this charge having a great tendency to reduce silicon as it melted, often giving rise to such a silicon content in the metal that hard gray iron was found on the melting down test.

As these classes of casting were being made as a high quality specialty the difference of a few dollars a ton in the conversion cost was immaterial, and basic operations was decided upon. The acid lining was torn down, and a basic hearth of magnesite burned into place as if for steel melting. After a few heats it was seen that the change had been a wise one as metal of exceptional qualities and with unusual qualifications was obtained.

### *The Basic Process*

The first result of using the basic furnace for making white iron castings was the reduction of defective castings to almost nothing, with the practical elimination of customers' complaints. As operations advanced the main features of basic melting were found to be:

Elimination of all former trouble due to analysis and control of the iron itself. The carbon and manganese could be held to narrow limits, while no trouble was experienced in keeping the silicons down on either heats from steel, or those in which a large proportion of the charge was returned shop metal.

Accurate regulation in temperatures was attained. It was possible to hold the metal indefinitely with no great changes, while the chemical composition was brought to the desired point. This feature was of great impor-

tance as often a heat would have to be held waiting on the molders for a rush, or breakdown job, where in the acid furnace silicon trouble always developed.

Extremely low sulphurs and complete deoxidation were obtained. The first result noticeable, and traced to this feature was the elimination of cracking or the display of tenderness in the molds. The second was a metal more free from inclusions or segregated spots, where patches of unequal hardness previously had been obtained.

No trouble was experienced in any manner with the wall or hearth refractories.

Slag control was more satisfactory, practically every heat pouring from a heavy carbide slag, due to the large amount of reducing material present in the bath.

The difference in time, power consumption, and cost were nearly equal for the two processes, and when the saving in lost castings was considered, was in favor of basic operation, as will be noted from the following:

	Time per ton	Kw. Hr.	Conversion
	Hours	per ton	per ton
Basic	1.46	705	\$12.30
Acid	1.29	730	\$13.60

Due to having more difficulty in clearing the basic slag from the ladles, during pouring on the floor, it took approximately 32.4 minutes to pour a ton of basic metal into the molds, as against 26.5 minutes for the acid iron. Later, use of tea spout ladles cut down this disadvantage greatly and bottom pour ladles would have resulted in equal figures.

While the figures on operations are those actually obtained, they would be of no use to any other shop as a criterion of white iron operations, as the furnace used in these tests was an old fashioned make, not well adapted to the operations. The shop itself was poorly laid out, resulting in a great loss of time. Later figures of approximately 525 kilowatt hours per ton of iron have been obtained with more modern equipment. This is

probably nearer the true figure required to melt this product.

### *Steps in the Process*

Before charging the scrap on a basic heat, the hearth is covered carefully with the slag mixture calculated to 2 per cent of the charge by weight. This mixture is made by grinding lime, fluorspar and anthracite coal in a muller, in the proportion of 75 per cent lime, 15 per cent spar, and 10 per cent coal. The recarburizer then is added being calculated to 3.00 per cent carbon, attention being given to the recovery of carbon from the different materials. This ranges from about 80 per cent for graphite flakes down to 50 per cent for the average grade of foundry coke. The selection of the recarburizer follows these precepts as described in the preceding chapter on synthetic irons.

The charge now is added, any good grade of steel scrap offering an excellent material, if fairly clean. Bundled tin-can scrap has been tried on account of its cheapness, but does not offer a metal of first grade qualities. As a metal of the lowest possible phosphorus, consistent with economic considerations, is desired, wrought iron does not prove as suitable as does steel of lower phosphorus percentages. The doors now are sealed tightly, being luted with clay, if this proves to be necessary, and the current is turned on. During melting the furnace may be kept heavily reducing by the addition, at slight intervals, of a small amount of coke if required. The condition within the furnace can be followed closely by the appearance of the flame, a sharp flame denoting oxidizing conditions, while the soft, brightly luminous flame denotes proper reduction.

As soon as melted, the bath is treated in exactly the same manner as if synthetic iron was being made, the carbon being raised by boiling with green wood poles,



or by rabbling. However, when the percentage of carbon is correct, slightly different procedure is followed. Instead of adding the ferrosilicon at once, the slag is brought to a finishing condition by additions either of lime, if thin, or spar if thick. As soon as the metal is under a heavy carbide slag, and one which thoroughly covers the bath, the doors again are sealed and the heat allowed to run for a sufficient length of time to bring the metal to a fairly high temperature. The silicon now may be added and the doors again closed. In about five minutes a metal test can be taken in a sand mold, and as soon as thoroughly set it may be water quenched and broken for fracture appearance. At the same time this quench test is poured, another in a sand mold should be cast and allowed to cool to a black, before being broken. This latter is for the hardness, and a heat never should be poured until the required hardness of the metal is attained.

### *The Appearance of the Fracture*

The proper appearance of such a fractured, slow cooled test piece should be a dead white, tending toward gray. The crystalline structure should be well defined, the crystals radiating from the center of the test piece. If the crystals are small, the carbon is not high enough and the bath must be boiled further under a blanket of carbonaceous material. If the least trace of a mottled appearance shows, the silicon is too high, and the steel scrap must be added until the fracture shows the hard, white color. If care is exercised in adding the ferrosilicon this mottled iron should be found rarely.

The castings poured from this iron was hard, but seemed to lack something in strength and resistance to shock. In certain practical tests made, the iron was not as good as it should have been. With the idea in mind of improving the physical qualities of the metal the use

of alloys such as nickel and chromium was made, and the effect noted.

#### *Alloyed White Irons*

The first alloy used in making alloyed white iron was nickel, heats being made with percentages ranging from 0.50 to 3.00 per cent nickel. It was found that nickel alloyed with the iron in all proportions, and offered nothing new in the melting methods. Certain peculiarities cropped out in the finished castings. It was found that the nickel seemed to retard the action of silicon in throwing carbon out of solution, and all the heats of an equal silicon content gave a much higher combined carbon content when nickel was used in the mix. At the same time, the iron appeared to be softer, and cases were found where the fractures of castings were a true white, yet the iron could be machined. As we desired a hard iron, nickel alone was discontinued and a combination of nickel with chrome was used. The same results still held and certain experiments were made to determine to what extent this retarding of the silicon would hold. It was found that irons with a silicon content as high as 1.75 per cent, and in several instances as high as 2.00 per cent would show a white fracture, yet would be machineable. One heat in particular, with an analysis of carbon, 3.22 per cent; nickel, 0.64 per cent; chromium, 0.44 per cent; and silicon, 2.32 per cent, gave a white fracture, and it was tried in a drill press. It drilled quite easily and the drillings seemed similar to those from a hard piece of steel in that there was a great tendency for the chips to curl from around the tool.

From the results it was found that nickel had a tendency to soften the iron regardless of the percentage present, 0.50 per cent seeming to give as soft an iron as when 3.00 per cent was used. This point seemed to follow regardless of the silicon content, until at percentages of the latter below 0.80 per cent the iron again turned

hard. Therefore, nickel gave no added characteristics which would make its use overcome the added cost of manufacture and its use was entirely abandoned.

Mayari pig iron, containing nickel and chromium, in a natural alloy was tried. The results were slightly different from those obtained with the pig nickel in that the softness obtained was not nearly so great, although there was an apparent softness to the metal after casting.

The next alloy used was manganese. This was used in many varying proportions. In high percentages such as 2.00 to 3.00 per cent, it had a tendency to close the grain of the iron, but seemed to possess no favorable points.

#### *Use of Chromium*

Chromium, up to this time, had not been used alone, and several heats were made using this alloy. Soon, it was noticed that the iron possessed new features. The fractures changed from a dead white to a lusterless color between a white and a faint gray, yet the iron could not be touched with a tool. The gates on the castings were not so easy to break as they had been with the other mixtures, and it was apparent that this alloy, when used alone, offered certain points which might be of importance, so that the trend of experimentation changed from the use of various alloys to that of determining the percentage of chromium which would best suit our needs.

The chemical and physical testing facilities of the plant being rather poor, it was difficult to determine what procedure to follow in determining the resistance to shock. Finally, it was decided to cast balls of 3-inch diameter from every heat, and determine the comparative number of blows necessary to fracture them. The method used was to hold the ball firmly on an anvil, and strike it with a 16-pound sledge until rupture occurred, the number of blows necessary to break the ball being taken as an indication of its toughness and resistance to shock. Only

one man was allowed to do the striking, and every test was made under parallel conditions as far as possible. While this test did not give any exact data, it did show which analysis of metal would stand the greatest shock before failing. This test was as close as possible to the exact conditions in a ball mill and as later results showed was a good indication of the amount of abuse the metal would stand in actual service. For testing the hardness of the various metals, a brinell meter was used, the test

Table XLIII  
TESTS OF ELECTRIC FURNACE IRON

Blows to crush	----- Per Cent -----				Brinell number	Mark
3	3.70	0.57	4.39	4.48	422	A
9	3.04	0.61	0.65	0.46	438	B
9	3.54	1.25	1.41	1.43	417	C
11	2.45	0.32	0.47	0.23	480	D
17	3.00	1.05	1.41	1.08	408	E
20	2.70	1.13	1.73	0.83	393	F
23	2.56	0.72	1.39	0.78	402	G
35	2.34	0.70	1.26	0.64	409	H
46	2.30	0.70	1.88	0.53	398	I
58	3.53	0.86	0.80	0.75	411	J

being taken from one face of a 3-inch ball which had been ground perfectly smooth. We had no available method of testing for wearing resistance so attempted to obtain a metal as hard as possible, and one which would stand the greatest amount of shock without breaking.

The results of these tests are given in Table XLIII. A description of the treatment of the specimens follows:

### *Results of Tests*

The heat, from which specimen A was taken, was made in the cupola and duplexed, the alloys being added in the electric furnace, and the heat brought up to tapping temperature under a heavy carbide slag, being held in this finishing condition approximately 15 minutes. Several heats were treated in this manner, but always with the low result, showing brittle iron, which seemed to prove the point that if it was poor as it came from

the cupola, it required a great deal more than this small amount of alloying, refining, and superheating to bring into a first class metal. The cupola charges consisted almost entirely of steel, only enough cast scrap being added to give fluidity, the iron often being almost pasty when added to the electric furnace.

Heats *B* and *C* were taken from the cupola and held in the electric furnace under a carbide slag for one hour each. While the results were better they showed conclusively that there was yet something which remained in the iron, due to the cupola melting, which mitigated against its toughness. The theory was advanced that oxide had actually dissolved in the iron during its travel through the cupola, and was in such a state of solution that the reducing action of the basic slag and superheating were not sufficient to free it from its combination, unless by such a long and tedious process as would prove too costly for its treatment. The theories on this oxide inclusions were strengthened greatly as every heat poured under the conditions mentioned cracked badly in the molds, often showing a line of gas holes along the break, giving rise to the thought that the pressure of solidification was so great that the gas was expelled and in so doing its force caused the still tender casting to rupture along the path of release.

To determine if this oxide or unknown constituent could be eliminated we made a duplexed heat in which the metal was held in a superheated condition under a perfect carbide slag, with the doors tightly sealed, for two hours. The results, specimen *D*, are practically identical with those held for only a short time, and proved that this long refining was but a loss of time and money.

Different classes of steel scrap melted down with no apparent attempt to greatly raise the carbon other than that initially charged gave specimens *F*, *G* and *H*. The lime slag was added after the melt down, the metal being

held under this carbide condition until superheated to the desired temperature. These heats were used to note if a change in the class of scrap caused any difference, the charges consisting of borings for one heat, first quality boiler plate and punchings for another, and clippings mixed with borings for the third. The results showed that the class of scrap made little difference if clean, and of a medium high grade nature.

Two type heats were made of the same charges, *I* and *J*, the best clean punchings obtainable being used, the heats melted from the start under a carbide slag, the test being to determine whether a low silicon with high carbon, or a low carbon with a high silicon gave the best results. This series of tests, when analyzed carefully showed several interesting points. Duplexing was not satisfactory, not only because of the cost of this method, but the desired quality could not be obtained. The worst fault was the defectives caused by oxides, consisting of such items as draws, blow-holes, cracked work, and iron of a brittle nature. The fractures of a failed casting from one of these heats showed a weak appearing structure, containing rather small sized crystals, with poor cohesion. This seemed to follow regardless of the final analysis of the metal.

#### *Low Carbon Iron Requires More Silicon*

Further, it was found when the total carbon in the iron was low it required a much larger amount of silicon to give equal results to an iron with a higher carbon content. These low carbon irons also exhibited a peculiarity in that irons with as high a silicon content as 1.50 per cent still would show a clear white fracture, with a comparable hardness to those standard white iron with an average carbon and low silicon.

Regardless of the exact chemical composition of the iron the most exacting care was necessary if proper

qualities were to be obtained from the casting made of duplexed metal. This covered particularly the melting and refining and clearly showed that the best grade of scrap steel must be used; that melting down conditions must be carefully checked and the formation of any oxides prohibited; and that the refining period required the same care as if a heat of special steel were being made.

These trials further showed that there were two general types of analysis, each of which gave comparable tests, and could be taken as representing the best metal, when viewed from the standpoint of toughness, and hardness number. These were as shown in Table XLIV.

These two types were segregated after analyzing the results from a large number of heats. After these were

**Table XLIV**  
SUGGEST MIXTURES FOR WHITE IRON

	Carbon	Manganese	Silicon	Chromium
Type X	3.00 to 3.50	0.70 to 0.90	0.70 to 0.90	0.60 to 0.80
Type Y	Under 3.00	0.50 to 0.70	Over 1.00	0.40 to 0.60

selected, many more heats of these two classes were made to determine if the choice had been warranted, and to determine, if possible which of the two was the better.

It was found that each class could be made easily and regularly and that the results were uniform, and amply proved the correctness of the first selection. Each type showed a clear white fracture on breaking, when cast into a 3-inch ball the latter type giving a white fracture with a silicon of nearly 1.50 per cent when the carbons were low. All fractures had a soft, dead appearance, and were close grained and tightly knit, the crystalline structure radiating clearly from the center of the ball. This radiating fracture finally was accepted as the best test of the iron's toughness, a casting with such a fracture always would stand a high test, while one

without this class of break usually would be more brittle.

However, the crucial test was the manner in which the two types would stand up in actual service, and for this test castings of the two different analyses were made and placed in operation, being run against each other as far as possible. Tests were made to cover all the desired points as toughness, hardness, and wearing ability. It was found that the shop tests had been a good measure of the toughness, and hardness, but that when the castings were subjected to the rigors of abrasive duty, type X was far superior. While there was no appreciable difference in the two irons as far as color went, it seemed that the silicon in higher amounts so changed the structure that a softening ensued, although analyses for combined carbon on the two types showed a close agreement.

With the analysis selected it was considered that it would be easy to obtain regular results with this iron. Operating the furnace with a charge of steel scrap, and under the standard series of operations as if making a synthetic iron, excellent results were obtained. The metal was always of a good, clean character, and high tests predominated. However, as soon as remelted shop scrap was used in the charge, trouble ensued. Here was a proposition different from that of building up the metal from raw steel.

### *Silicon Exerts Strong Influence*

In the first place, the alloys already are contained in the metal in the proper proportions, and in the second place it proved difficult to estimate the losses of the various constituents during the melting down period, this factor depending upon the size of the individual pieces, their condition of oxidation, the rate of melting, the amount and condition of the slags, etc. Slight variations in the carbon, chromium and manganese were found to have little effect, but changes in the silicon content caused trouble. If too low, the metal was weak, and if too high the iron would be



soft. As it was extremely difficult to operate for silicon under close chemical control, due to the length of time necessary for the chemist to make an analysis for this element, we were forced to estimate on the percentages of this alloy present. To assist as much as possible, the heads and gates from each heat were separated and held until an analysis had been made. Each pile being thus closely known it became a matter to control the analysis closely. After checking a few heats, the losses of the different elements were determined. It was found that the average losses were as follows: Manganese, 0.10 per cent; silicon, 0.20 per cent; chromium, 0.20 per cent and carbon, 0.05 per cent.

Many trials showed that these losses were close, and were exact enough so that if estimated on this basis, the heat would prove within specifications. These figures were for heats containing 100 per cent of shop scrap, of a medium size, and in a clean condition.

The analysis being controlled, it still was found that results from shop scrap were not good. Many heats were poured of practically exact compositions yet one would be excellent, while another would be extremely brittle. Close checking showed that on the heats which were good the fractures of the gates had the radiating structure while brittle heats showed the soft, feathery, structure without distinct crystalline outline.

With this idea in mind, several heats were poured and the test fractures closely noted before tapping. It always proved true that on the heats where the furnace test bar showed a radial structure, the castings were of extremely high character, while on those fractures showing a feathery grain the exact opposite held. The problem then presented was always to obtain this structure before tapping and the trend of experimentation turned to the solution of this trouble. Appendix table 28 gives the log of a heat of alloyed white iron.

That the presence of chromium in remelted heats often resulted in poor results was known, since this point was shown by the writings of an Austrian author covering the manufacture of gun steel from remelted stock. He noted that chromium often, from no apparent reason, resulted in steels of a crystalline character, when one of fibrous structure was desired. This often was attributed to the presence of oxides, but his experiments demonstrated that it was not oxides, but the chromium that exerted some peculiar influence. The exact cause or the exact solution of this peculiarity never was discovered.

#### *Melting Chromium Alloy Scrap Difficult*

The author's results were similar, even though on iron. Heats made from remelted white iron which contained no chromium gave good results when the chromium was added as an alloy, but as soon as this chrome iron was remelted trouble ensued. This appeared periodically and as it was absolutely necessary to use this metal, a serious matter was presented. Many trials were made to obtain the solution of this trouble. Heats were melted with slags, and without slags. Carbon was added with the charge after the melt down. The heats were melted as fast as possible, and slowly melted. Heats were melted under perfect reducing conditions, and others were melted and heavily boiled with green poles. In fact every known metallurgical trick was tried, but with no success. The fact remained that if a heat gave the soft fracture, it could not be poured into heavy duty work.

This problem never was solved, the heats being so arranged that if a radial fracture was obtained, the iron was poured into high test work, otherwise a grade of standard white iron castings was poured. As these heats occurred only about one in ten, the shop scrap was segregated carefully until sufficient was on hand for a heat, when it would be melted and poured into castings which did not require the resistance to shock property to a high

degree. As this iron still retained all of its qualities except toughness there were a great many types of casting for which it proved excellent. All such work as ball mill liners, balls, etc., was poured from an iron made directly from the steel, so that no difficulty was encountered in maintaining the high shop standard.

### *Pouring Practice*

When the heat is poured into the ladle, a skim gate always should be used, and the ladle held at least 5 minutes before a mold is poured, that any included slag, coke or other non-metallic impurities may clear themselves from the metal by rising to the surface. The author has found that about 5 pounds of finely crushed fluorspar added to the bottom of the ladle before the furnace is tapped aids this operation by combining with any slag and so lowering its melting point that its fluidity is increased and it clears itself from the iron quickly.

Final deoxidizers such as titanium, magnesium, calcium compounds, etc., have been tried, but do not seem to add anything worth while. The use of vanadium, uranium, and zirconium has been suggested, but never have been tried.

Ladle troubles with this heavy basic slag will be the same as for gray iron, requiring the use of bottom pour, tea-spout or other system of ladles where the slag may be separated from the metal.

The size of the pouring gates and heads may be much smaller than is customary for cupola iron, due to the extra fluidity caused by higher pouring temperatures. A higher grade of refractory sand for molds and cores is necessary for the same reason. The high shrinkage of this iron necessitates great care in the molding to prevent undue cracking. Immediately on pouring, quick work must be done to relieve any strain in a casting by digging around the heads, loosening the copes, etc. The use of

wood filler blocks, rope wrapped cores, coke and sawdust inserts, etc., finds wide favor in keeping the percentage of losses down. For small work the buzzer or automatic skim gate finds wide application.

Castings should be allowed to cool in the sand as far as possible, and under no condition should a casting be taken from the mold and quickly cooled, either in a draft of air or in water. If such a treatment does not directly crack the casting it is sure to set up internal strains of such magnitude that the piece later will fail in service, possibly with disastrous results. In the design of patterns, sharp corners should be avoided as far as possible, as these angles are starting points for cracking. Often on certain classes of work where square holes are essential, as in certain ball mill liners where a square headed bolt hole is used for rigidity, a further treatment is given to relieve the strain.

#### *Heat Treatment of Alloy Castings*

The treatment is similar to that followed in annealing steel castings, but is not intended in any manner to change the grain structure, and has no effect on the hardness of the metal. The castings are heated to approximately 500 degrees Fahr., and allowed to soak until the heat is uniform through the piece, when slow cooling is followed. Such treatment aids the strength of the work and castings so treated have shown extraordinary features of toughness, and resistance to shock, especially when the generally brittle character of this metal is considered.

#### *Alloying Gray Irons*

Alloys are used in producing quality gray iron mixes for the electric furnace. The greatest impetus to the use of alloys in gray irons was imparted by the discovery and commercial manufacture and sale of a natural alloy pig iron, placed on the market by the Bethlehem Steel Corp.

coming from the province in Cuba where this natural alloyed ore is mined. This ore and the resultant pig contain chromium and nickel, always occurring in a certain ratio. Its use when developed and tried gave certain interesting features to the casting so made. It was found that iron castings made with this pig were soft, and readily machinable, yet at the same time were of a close grain with high strength. The iron found extensive use in hydraulic castings where a high strength iron with a close, tight structure was desired to resist the flow of liquids at high pressures through the walls. The results have been so good that its use has extended to a large number of such castings, one great class being automobile cylinder blocks.

#### *Properties Given by Adding Nickel*

The high character of the results obtained with this metal led others to make extensive experiments with various alloys to determine if there were any exceptional properties to be obtained from their use. Of these alloying metals, nickel probably has been tried more than any other metal. Its action in steel being well known it was expected that similar properties might be found when used in iron. While the results were different, it was found that the use of nickel was helpful, especially in certain classes of work. When used in gray iron, nickel offers certain unique properties:

Nickel has the faculty of softening the metal even in the presence of high percentages of combined carbon, results having been given where an iron with 1.25 per cent combined carbon, containing approximately 4.00 per cent nickel, was capable of being cut easily.

Its influence seems to be identical with silicon as far as its ability to soften the iron extends, yet it accomplishes its purpose with no decrease in the strength of the iron, a point directly opposite to that of silicon.

It tends to close the grain of the iron, giving higher

strengths at no expense to the machine shop in more difficult machining.

Nickel has the property of throwing carbon out of solution rapidly during the solidification, a point which makes this metal desirable in extremely thin walled castings, as it avoids any tendency toward chilling during the cooling period, which would cause the iron to become white.

Thin section castings containing from 3 to 4 per cent nickel may be bent and twisted to a certain degree taking a permanent set upon releasing the pressure.

By far the best results on metal with nickel additions are obtained through the use of the basic process, in that low sulphur content and thorough deoxidation are possible. As this metal usually is cast into a high priced product, a few dollars difference in the cost of conversion is negligible when considered in the light of the high quality desired. The ordinary charge consists of pig nickel together with pig iron or high grade iron scrap. In mixtures where low phosphorus is desired, the greater proportion of the charge will be a low phosphorus pig iron. Best results are obtained when melting under a carbide slag from the start of the heat, consequently lime is added to the furnace with the charge, together with a small amount of carbonaceous material to furnish the necessary reducing atmosphere.

#### *Graphite Separates at Beginning of Heat*

After the heat has melted a certain peculiarity will be noted. This found only in these nickel mixtures. A heavy separation of graphite from the metal is encountered as soon as the metal is thoroughly fluid. This resembles the separation of *kish* in blast furnace irons, but offers no difficulties, for as soon as the metal has been superheated this carbon rapidly returns to the iron, being soluble at high temperatures. As soon as this graphite deposition occurs, the doors should be sealed tightly and the furnace run for at least 15 minutes when a quick ex-

amination will disclose whether or not the re-solution has occurred. If not, more time is required.

There is no opportunity for close chemical analysis on such heats. Therefore great care must be exercised in the selection of the charge and furnace tests must be taken in a different manner. The spoon test is used to determine the temperature, but the metal instead of being poured into a square bar is poured into one of a wedge shape, capable of being split when black. This gives the fracture of the metal, and the amount of chill obtained in different sectioned castings. Knowing the desired structure of the metal for a certain class of work, it becomes easy to change the metal so that its character is that desired for any given section. This is done rapidly, either by the addition of small amounts of silicon, if the iron shows too hard, or by adding small proportions of steel for the softer fractures.

With the high percentage of nickel used, this iron has a higher melting point than its comparative nickel free mixtures and requires higher pouring temperatures. The electric furnace offers perfect conditions to attain this end. These alloyed heats are poured at temperatures close to those for steel, usually being tapped 2800 to 2900 degrees Fahr., which is extremely high for iron.

#### *Tests on Nickel Irons*

In *Stahl und Eisen* of Sept. 30, 1920 some figures appeared covering results when nickel and cobalt were used in mixtures of gray iron. The authors used lower percentages than those mentioned in this section, namely from 1.00 to 1.50 per cent nickel. They state that they find 1.00 per cent nickel increases the bending strength approximately 30 per cent, the compressive strength, 30 per cent and the tensile strength, 18 per cent.

The use of cobalt was attempted, 1.00 and 2.00 per cent of the alloy being used. Results obtained were di-

rectly opposite to those obtained from nickel, the hardness increasing rapidly while the bending strength, the compressive strength and the tensile strength decreased. Therefore, the results were negative conclusively showing that cobalt does not offer any possibilities in its use for gray iron.

### *Effect of Zirconium*

Moldenke at the Columbus meeting of the American Foundrymen's association, in 1920 gives some data covering the use of zirconium. It was found that its use was negative unless high temperatures of the iron were obtainable, the alloy seeming to require a high temperature to start its de-oxidizing reaction. When used in small percentages, in the form of 30 per cent ferroalloy, the results were fair, but larger percentages seemed to chill the iron so that results were negative. He gives some figures as follows:

#### **Gray Iron Mixture**

60 per cent pig iron, 40 per cent scrap. Averages from 3 bars each.

Breaking strength, lbs.	Deflection, inch	Zirconium added, per cent
2700	0.10	none
2920	0.11	0.05
2900	0.11	0.10
3050	0.11	0.15

#### **White Iron Mixture**

60 per cent car wheels, 40 per cent white iron scrap. 3 bars.

Breaking strength, lbs.	Deflection, inch	Zirconium added, per cent
2640	0.10	none
2790	0.10	0.05
2880	0.11	0.10
2940	0.11	0.15

From these figures it can be seen that zirconium offers nothing startling. With the higher temperatures obtainable in the electric furnace it might be possible to obtain more advantages by using larger percentages of alloy, a point which later research may prove.



*Use of Molybdenum*

Molybdenum is finding considerable use in iron castings of late years, especially in chilled rolls. Rolls for mill work are important in that an accurate check is kept upon the service given throughout the life of the roll. The roll which gives a longer period of active service naturally is the one which will be in greatest demand. Roll makers faced with such a proposition have turned to the use of any alloy which would give a superior product. The use of the molybdenum is a result of this research.

This element finds its greatest asset in its accurate control of the depth of chill. It seems that its use promotes a more active metal, one which is sensitive to the effect of a chill. This results in the possibility of being able to make rolls in which this desired chill may be controlled to an exactitude not possible with the ordinary and more sluggish mixtures. As the depth and character of the chill on a roll is the most important point in manufacture, molybdenum seems to have been a great aid. This also has been used to some extent in car wheel manufacture, but no information is available concerning its value.

*Vanadium and Other Alloys*

Vanadium has been used in iron mixtures, and confers certain helpful properties. Its main asset is in slightly closing the grain of the metal and in throwing out the graphite in finer and smaller flakes. This gives a soft, and readily machinable iron which may be used where high speed production is necessary. Whether these properties can be obtained at a cost commensurate with their importance is yet undecided.

Cerium, uranium, titanium, etc., all have been used at various times in gray iron castings, but their use has been experimental, the result being of such a character that no further attention has been paid to their commercial use.

## XV

### LADLES—THE TYPES AND THEIR CARE

ONE of the most important, yet least considered points in the majority of modern steel foundries is the care and preparation of ladles, and the practice followed in pouring molds. Many castings are lost through gross carelessness or lack of knowledge on these details. In some shops the actual pouring is under the direction of the melter. In others the foundry foreman supervises this feature. Unless the practice is well established difficulties ensue. The melter knows the temperature and condition of his metal, yet may remain in ignorance as to the peculiarities of each casting poured. On the other hand, the molding foreman knows exactly what is in each flask poured. Further, the molding foreman may be ignorant as to the characteristics of this particular heat of metal. The evident result is that some molds are poured too slow, others too fast, hot metal may be poured into castings requiring the deadiest sort of steel and so on.

Even when the person who supervises the pouring possesses sufficient knowledge and discrimination to judge the pouring operations, ladle trouble, with its many obstacles often arises to throw out of gear all previous calculations. Pouring the heat is as important as the making of the steel itself, for what value is excellent steel if the mold is spoiled by improper handling. As in most foundries the furnace operator is in direct charge of the ladles and the pouring it has been thought wise to include some data on this subject.

#### *Types of Ladles*

Three main methods are used for handling steel from the furnace to the mold at the present time. These are the common lip-pour ladle, such as predominates in

iron foundry work, the tea-spout, and the bottom pour ladles.

The lip-pour ladle consists of a brick lined steel pot, suitably arranged with gearing to tilt it. This type ladle has been adopted through familiarity with iron foundry work for many years. The ladle offers certain advantages. There is a certainty of being able to pour the heat with no difficulty from a leaky stopper, or any chance of the spout freezing as with other types. The one in charge of pouring is able to tell with great certainty the amount of metal remaining in the ladle after a great part of the heat has been poured, with its attendant saving in castings poured short. Finally, accurate control of the stream of steel being poured into the mold is possible.

#### *Disadvantages Are Greater*

These merits pass into insignificance when the disadvantages are studied. In the first place, the steel, as it continually pours over the lip, always is in contact with the cold air, the result being that there is a rapid chilling effect on the metal. This requires that the metal be heated to higher temperatures with increased cost. It results in more ladle skulls, and more castings lost from cold metal, both of which are costly. The second important count against this piece of equipment is the great difficulty in keeping the slag back during pouring. Often considerable quantities of slag enter the mold with the metal and result in defective castings.

As high heats are necessary, the ladle itself must be highly heated. This requires more oil, which with the hotter metal, and heavy skulls give less tonnage on a ladle lining. These disadvantages are such that the use of this class of ladle is rapidly declining. Lip-pour ladles today are used mostly in shops where a small amount of metal is poured at one time, or in those under the direction of old school foundrymen.

The tea-spout ladle consists of an ordinary lip-pour

ladle with an attachment similar to the spout on a coffee or tea pot, from which its name is obtained. This supplementary spout is so arranged that the metal from the bottom, or near the bottom, of the ladle passes up through this spout and is poured. This means that the metal is taken from under its covering of slag and has two main advantages: First, there is little trouble due to slag interfering with the flow of steel over the lip. Second, the blanket of slag covering the steel is not disturbed and aids greatly in keeping part of the heat of the steel within itself. This does away with one of the main counts against the lip pour ladle, yet the majority of the disadvantages inherent in the original ladle still are contained in this later modification. There is a great tendency for the metal to get cold and freeze in this tea-spout. The ladles must be highly superheated, as must the metal also. In short, this type of ladle is nothing but a self skimming lip-pour ladle with all the weak points of the latter. Such ladles, on account of the surety of pour, are widely used and may be considered as a common piece of steel foundry equipment.

#### *Bottom Pour Ladle*

The bottom pour ladle has been in use for many years, especially in basic, open-hearth steel work, where great care must be used in the separation of slag from steel. This type of ladle is exactly like the lip-pour ladle except that the metal is poured through a hole in the bottom of the ladle itself. This hole is made by inserting a special brick in the ladle bottom and tightly ramming it into place. The top end of this brick has a circular depression into which fits the end of a long, covered rod, known as the stopper rod. This rod is so arranged on a system of levers that it may be raised and lowered, opening or closing the bottom opening in a manner similar to removing and inserting a cork in a bottle. Such an apparatus has the following manifest advantages:

As the steel is taken from the bottom of the ladle, there is but little possibility of ever obtaining slag in a casting.

The slag, after it is tapped, forms an air tight blanket over the surface of the metal, and during the pour is not disturbed. The main result of this is the slight loss of heat from the metal, consequently the steel may be poured throughout the pouring period at much higher temperatures than is possible with the other types of ladle.

Due to this arrangement there is no skimming to be done during the pour. This gives a saving in labor.

With the great saving of heat in this method, there is no necessity for heating the ladle to such high temperatures before the metal is tapped into it, making a considerable reduction in the amount of oil used for ladle heating.

With the possibility of less heating before the metal is tapped, and with the ability to pour much colder metal successfully the life of such a ladle lining is greatly prolonged, making the refractory cost considerably less.

With less chance of skulling, the amount of labor to reline and keep such ladles in repair is far lower than on the other types.

As the temperature of the metal remains higher during the pour than with the other ladles, there is considerably less skulling, less spilled metal, and much less metal cast into pigs when too cold to run a casting.

Due to the ease of handling such a ladle, less time and less labor are required to pour a specified amount of metal than with the others.

In certain instances a large nozzle brick may be used, and metal can be poured into large castings, so cold that it would never get over the lip of the other classes of ladles.

However, it is but natural that this type of ladle should also have its disadvantages. As with the tea-spout ladle, there is more uncertainty to the pour, caused by troubles with the nozzle leaking, the rods burning through, etc. Cost is increased each heat by the amount of one stopper head, one nozzle brick, and 5 or 6 sleeve brick, plus the extra cost of upkeep on the rods, pins, etc. It is

difficult to know the exact amount of metal left in the ladle toward the end of the pour. This increases the chances of pouring a casting short. There is a certain amount of uncertainty in knowing the exact temperature of the metal until the stream is started, often causing hot metal to be poured into a large heavy mold. As this is more carelessness than the fault of the ladle it cannot be used as a count against this type of equipment.

Personally, the author knows from experience, that the advantages of the bottom pour ladle are so great that a shop should not be considered as turning out a high grade product unless such equipment is used. Not only is this ladle far superior from the standpoint of quality, but it is far ahead of the other types in cheapness of operation. While it is true that the rod equipment costs more per heat, the great saving in other items far overbalances this slight cost. The speed and ease of pouring, the lack of spill, skulls, pigged metal, less labor, etc., constitute great economies at the end of a year's operation.

The other side of the story is this:

"Yes we have tried bottom pour ladles, but they gave us so much trouble that we had to quit them. They may be all right, but we cannot take any chances with our product."

The trouble with the objector in such an instance is this. His shop has tried the bottom pour ladle, but in the hands of a man who did not know how to operate one, or under the supervision of a melter who was not acquainted with the peculiarities of its operation. One would not expect an automobile driver to step into an aeroplane and do stunt flying at once, so why expect a green man to operate something which is difficult even to the experienced ladleman.

The efficient operation of a bottom pour ladle is an art, and one in which as much experience is required as in successful steel melting. It is perfectly true that

trouble is encountered due to leaky stoppers, etc., but what can be worse than a frozen tea-spout, or a frozen lip pour ladle, or a heat where a great part must be poured into pigs. The author has supervised bottom pour ladles for many years and has had his troubles, yet they were insignificant when the perfect heats are considered.

#### *Maintaining Ladles*

Regardless of the type of ladle used, there are certain points in which all are equal. The first question which confronts the new shop is whether to use a rammed ladle lining or one of brick. While the writer favors the brick lined ladle, there are many successful shops that use nothing but rammed linings. Personally, the author has found the brick lining is better in service.

If a rammed lining is to be used, it will be necessary to build a wood form with a diameter such that when placed in the ladle, it will allow the desired thickness of lining around the sides. This form is best made in sections so that as the bottom section is rammed, the height may be raised. This allows better and harder ramming for each successive layer, making the lining more homogeneous and of a more durable character. The bottom of the ladle should be laid of a good quality fire brick, usually two rows laid flat being used, and properly cemented into place with fire clay or with some good refractory cement. The wood form then is placed in position and the refractory material rammed around it until a section the depth of the form has been rammed. Another section is placed in position and this operation is repeated until the material has reached the top of the ladle. The different classes of refractories used are so many that it is needless to enumerate them, but nearly all consist of some sort of a ganister mixed with a binder such as glutrin, sodium silicate, or some refractory cement, mixed to a stiff mud and tightly rammed, in a manner similar to placing an acid hearth in place. In cer-

tain instances, where a basic lining is used as in manganese steel ladles, a mixture of magnesite is used with a proper binder.

After the ladle is completely lined, it is allowed to stand for several hours, often over night, until the refractory has had a chance to air set. Then the form carefully is removed and a low fire is started in the ladle. This heat is gradually increased until a hot fire is attained in the ladle. This is continued until the lining has dried thoroughly. The fire never should be forced at the start as this will result in scabbing the refractory and often will cause large patches to spall off. Generally six or eight hours are required to thoroughly dry a 3-ton ladle, the usual method being to start the fire about noon, run slowly until 3 o'clock, when the fire is increased, until at about 4:30 it is extremely hot. Sufficient coke then is added to keep the fire all night, the ladle being dry next morning, and only requiring the oil flame to set the refractory. The flame is placed on the ladle and it is run until white hot, and dripping if possible, when it is shut down and the ladle is ready for steel.

### *Lining Ladle With Brick*

The bottom is placed in the same way in a brick lined ladle, but the walls are formed of arch bricks, shaped to fit the contour of the ladle, and laid in a heavy mud so that no cracks remain. When completely lined a fire is started. This may be run high from the start with no danger from spalling. After the ladle is thoroughly dried the mud is plastered over the joints and every crack filled when it is ready for its first heat. The great advantage of a brick ladle is its strength throughout the mass, with no tendency toward spalling of large patches, or to crumble under increased heat.

After every heat, ladles should be chipped carefully to remove small metal skulls and adhering slag. Any



small worn spots should be mudded. As soon as a ladle develops a spot which is thin, or which looks dangerous, it should be removed and new bricks placed in position. About two inches of molding sand is rammed over the bottom to protect it from the falling metal stream. This should be inspected carefully after every heat to make sure that it has not cracked or that there is no metal hanging. Small skulls left in a ladle are a prolific source of trouble and often cause the metal to chill around them resulting in serious freezing.

### *Preparing for Steel*

Assuming that the ladle is lined, the bottom placed in position and thoroughly dry, the next step is the actual preparation of the ladle for the steel. If a lip pour ladle, the requirement is to form the lip itself, which is best made in the shape of a deep rounded V, over which the steel will pour in a light stream, its amount being controlled easily.

For tea-spout ladles the spout itself must have attention. This is lined like the ladle, but usually is made of some rammed material, as it must be changed after every few heats. The spout may be made in two ways, either outside of the ladle proper or inside of the ladle. The outside lip has certain advantages in that it is accessible, through having a removable face plate, in case of having to remove a frozen stub from the spout. For this case a counterweight is required on the opposite side of the ladle, and a little more difficulty is encountered in pouring the steel, due to the heavy off center overhang. Regardless of the position of the spout relative to the ladle, it will consist of a long tube, probably 4 or 5 inches in diameter, connected with the body of the ladle by an open space through which the metal can enter this pipe. In heating, this class of ladle always is laid on its side against a wall with the spout up, so that this section of

the ladle is the hottest. Such a ladle will give trouble unless the spout is white hot before the metal is tapped into it.

On pouring from such a ladle, a few large castings should be poured first so that the metal running over this lip and up through the spout, may have a chance to heat the colder sections which are exposed to the air. As soon as the spout is hot and the steel pours clean over the lip, smaller castings may be poured, until the metal begins to chill when all haste possible must be used to get the metal out of the ladle. In case of the spout freezing there is nothing which can be done except pour the metal over the opposite lip. For this reason, a good lip should always be provided on the side opposite to the spout for just such emergencies.

Tea-spout ladles find their widest use in the smaller shops where metal in amounts under 3 tons is poured at one time, although the writer knows of several operating in shops pouring up to 7 or 8 tons at a time where a large amount of this metal is shanked from the large ladle to pour the side floor work.

#### *Bottom Pour Practice*

In making the bottom of a bottom pour ladle a small hole is left over the nozzle plate, this hole being approximately 12 to 14 inches square. The nozzle plate is a ring shaped plate bolted to the ladle bottom upon which the shoulder of the nozzle brick rests. When the nozzle is set, it is placed in the center of the hole resting on this plate, and in an exact perpendicular position. Tempered molding sand is rammed tightly around this brick to hold it in position, the sand being so rammed that the brick is at the lowest portion of the ladle, the bottom sloping gradually up and away from this brick. This assures a clean drain of the metal from the ladle and prevents bottom skulls. This brick never should be allowed to be in a hole in the bot-

tom with abrupt walls, for if so placed there is the chance that the rod during the pour, might slip sideways a little, and the hole would be so steep that it would not slip back into place. This would result in serious run out.

Setting the nozzle is an important operation and the greatest of care should be exercised in the selection, testing, and placing of the brick. These nozzle bricks are



Fig. 55—Surface Defects in Nozzle Bricks are Ground by a Cast Iron or Steel Grinder of Exact Stopper Dimensions and with a Nicked Grinding Face

so designed that the upper portion of the face is concaved, and it is around the rim of this section where the stopper rod fits to seal the opening. The brick selected should be one which has a smooth face and it should be tested for its correct contour before setting.

#### *Fitting the Stopper*

The method of testing such a brick is to place it on a bench and setting a standard stopper head on it in the

exact position which would follow if in the ladle. This head is rotated against the brick, with a slight pressure, and the black ring caused by this contact observed. If this brick has a perfectly round and uniform face, the ring will be a perfect black circle. If not, bare spots will show, denoting either small lumps or depressions in the brick's surface.

If the lumps or depressions are slight it will be permissible to use a grinder to bring the surface to its proper shape. Such an implement is shown in Fig. 55. This consists of an iron or steel casting, of the exact shape of a stopper head, being machined to these dimensions. The upper or bearing surface is nicked with a chisel so that as this head is rotated against the rough surface of the brick its abrasive action is such that it wears away the uneven spots and brings the brick to such a shape that the fit of the latter head is perfect. Too much grinding is not permissible as the absolute removal of the bricks' surface offers a soft spot

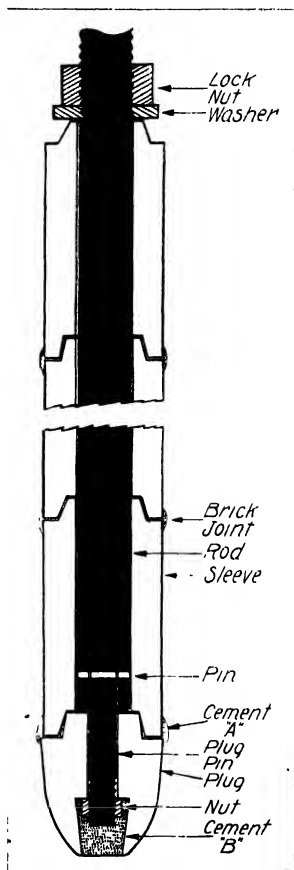


Fig. 56—Stopper Rods are Built up of Hollow Refractory Sections Supported on a Central Rod and with the Joints Cemented

which will be cut away under the influence of the hot steel. As soon as the shape of the brick is such that a perfect fit of the stopper head is assured, by the absolute regularity of the black circle, the head is placed on the brick and a small amount of dry fine sand placed around the head where it rests against the brick. If the joint is tight enough to hold the sand, the fit is satisfactory, and the nozzle is ready for the ladle. A nozzle never, under any circumstances, should be used without this sand test.

Bricks will be found which are so uneven that they will require heavy grinding to bring to shape. These bricks may be saved for use on heats where only one or two stops are to be made which will take the greater proportion of the heat, so that there would be slight danger of trouble even though the stopper allowed a light dribble after the first opening. When the nozzle brick is rammed into place in the ladle care must be used to see that the brick is centered properly on the nozzle plate, that it is absolutely perpendicular and that the ramming is so tight that there is small chance of the brick working loose and allowing leakage.

### *Preparing the Stopper Rod*

After the nozzle is set properly for the bottom pour ladle, the next step is to set the stopper rod. This is as is shown in Fig. 56, and is prepared in accordance with the following procedure. The first step is to note if the iron rod is straight and if the threads are in good condition for the nuts. If so, the stopper head is placed in position on the lower end of this rod by the pin as shown in the illustration. After the pin is in place, the head should be rotated until the nut tightens, giving a tight fit against the lower end of the rod. A handful of either mud, fire clay, or some good refractory cement is rubbed around the top of this graphite head when the first sleeve brick

is placed in position and forced as tight as possible against the stopper head. This same process with the mud is used between each of the bricks until the rod is filled as high as desired. The washer then is put on and tightened with a nut until the rod's coating is tight and the cement is being squeezed from the joints. Then the rod is placed on its side and given a coating of the cement, this being rubbed on by hand, and sufficient in amount to fill any small openings between the bricks.

The best material the author has found for the joints is any refractory cement. These have the ability to resist heat in operation, and also have a natural tendency to bind in place, and do not flake out as is the case with fireclay or mud. Furthermore, when the ladle is being dried, they will heat without cracking badly.

It is unnecessary to mention that the sleeves used should always be in first class condition, and fit snugly into each other, and over the stopper head. As each brick is laid, it is good practice to fill the space between the iron rod and the brick with sand, that any slight leak may be stopped before it has a chance to attack the rod. A rod never should be used unless every joint is perfectly tight, as a loose fit is an invitation to the metal to enter, often with bad results.

When the rod is finished, the opening in the bottom of the stopper head should be plugged. This stopper head is graphite and naturally rather soft, with a tendency to give. The greatest trouble is to find some plugging substance which will stand the heat and the action of the metal without burning, and yet at the same time will have an expansion close to that of the graphite so that it will not fall loose when the rod is heated. Many substances are on the market for this purpose, but a satisfactory material may be made in the shop. Take the old stopper heads as they are used and pulverize them. To this powder add sodium silicate until a stiff mud is formed.

This is forced into place with the fingers. When a plugged head of this cement has passed through a heat, it is absolutely impossible to tell where the joint has been made, so intimate is the connection. Such a cement will resist heat and the flow of the metal exactly the same as the head itself, and as it is made of the same material it has the same expansion, so that there is never any trouble encountered on this point.

The rod being finished, it is necessary to dry it thoroughly before use. This can be done in almost any oven. In the open-hearth shops, they are dried by leaning against the hot furnace. Some shops dry their rods in the core ovens while others have specially made ovens. Regardless of the equipment, the rod should be dried slowly and when used should be still warm.

### *Setting the Stopper Rod*

When a ladle is being made ready for use, the rod always is set before the ladle is heated. The rod is fitted to the gooseneck and so arranged that it will have plenty of play during the heat, note being taken of the fact that the head wears off as the heat progresses and sufficient allowance in added length is taken to cover this feature. The rod is tried several times to assure that it will slip into place easily when the lever is lowered. It then is placed in its final position and again tried at the joint with dry sand. If any comes through, the brick should be cleaned carefully and tried again. If sand still leaks, the rod must be rotated against the brick to fit the head into brick shape which usually will give a good test. As the brick has been tested previously there should be no difficulty on this point, although often a small piece of dirt from the ladle wall will fall and stick against the brick, causing the first leak. As the rod is ground into place, this is forced out and a tight fit results. The rod

being satisfactory it is removed and the ladle is ready for heating.

A small piece of steel plate should be placed over the nozzle brick to prevent any possibility of dirt or mud falling and sticking to this brick, or clogging the opening. If this steel has a lug attached with a hole in it, its removal by a long hook is easy. The flame is lighted and the heating of the ladle begins. Bottom-pour ladles always are heated from the top, and commercial types of burner are satisfactory for this purpose. A bottom-pour ladle does not have to be heated to a high temperature, but just enough to insure complete dryness, and to take any chill from its body.

Experience has shown that it only requires 15 to 20 minutes of the flame to prepare a dry ladle for a heat of steel, any time over this period only results in a waste of oil or gas. This type of ladle may be over-heated, resulting in running either the walls or the plate over the nozzle. If any running occurs it is likely to go against the surface of the nozzle resulting in a poor fit with later trouble. If a ladle is thoroughly dry it needs only to be brought up to a dark red. The rod may be finally set 10 or 12 minutes before the pour, when there is plenty of time to insure a careful job. A ladle never should be brought to the furnace for steel without the final sand test.

#### *Encountering Trouble*

The foregoing has covered in a general manner the method pursued in the arrangement of a bottom pour ladle preparatory to tapping the furnace. Troubles are bound to happen, but as they are the result of nothing but gross neglect it is best to mention them specifically so that the shop entering this field may be forewarned, and thus armed.

Rod brick splitting is a difficulty caused by only two things: By the nut on the rod being so tight against the



brick that there is no chance of expansion being taken up, the pressure breaking the brick; or by the rod being still moist, the steam actually blowing a brick apart when the hot metal strikes it. The result of such an occurrence is that the bare iron rod is exposed to the metal, and if the heat is in any way hot, or medium, the result will be that the metal will burn the rod through, and it will be necessary to finish the pour over the lip.

To avoid as far as possible such an accident, the greatest care should be taken in drying the rods, and the ladleman should be certain that the rod is perfectly dry before it is set in the ladle. The best method of covering this item is to keep all the made-up rods in a certain oven, having at least three or four days supply set at all times. If a system is arranged whereby the rod used has been in the oven three days or more, and is still warm before use it is practically certain that there will be no trouble from moisture.

To avoid any chance of expansion breaking the bricks, the lower nut should be loosened just before the ladle is brought to the furnace allowing at least one-quarter of an inch. As the brick will heat and expand much faster than the interior iron rod this lengthening must be compensated. If the lock nut is sufficiently loose the brick, as they expand, will slide along the rod easily for the small amount of increase due to their rapid heating. If the rod has been made properly there is no danger of the metal lifting the bricks and causing an opening in a joint lower down.

Rod or slag boil is an occurrence that will be found only on heats made by the basic practice, and more especially on those where the slag is of a highly cutting nature, and extremely hot and fluid. This trouble will manifest itself within a few minutes after the metal has been poured into the ladle. A small boil will begin around the rod at the slag line, and may increase in intensity so as

to throw considerable slag from the ladle. If the upper layers of the rod are moist, this boil may become violent and at times absolutely dangerous. If such a boil is allowed to continue it will slag off the upper brick, and the hot slag will eat through the rod itself.

The remedy for any such condition is to throw several shovels of lime around the rod as the slag comes from the furnace. This will harden and thicken the slag so that there will be small chance of its tending to slag away the rod brick. Naturally a heavy basic slag will eat away the acid rod brick as the heat progresses, but as this slagging action is not centralized, but extends over the entire length of the rod it is seldom the cause of any serious trouble.

A stopped nozzle will manifest itself at the first, when the ladle is opened only a dribble, or often no metal at all will come forth. This is caused by something having dropped and closed the opening in the nozzle brick, while the ladle was heating. If just before the final setting of the rod a bar is thrust down through the opening there will never be a chance for this to occur, as any small amount of ladle lining, or dirt will be broken loose. One of the methods of preventing this trouble has been mentioned, using a small steel plate to cover the nozzle while heating the ladle.

If such trouble occurs on the floor, the only remedy is to shut the opening quickly so that there is no chance of metal dribbling down and freezing the opening, and use a pricker to open up the nozzle brick. If dirt can actually be seen, a pointed iron bar will be satisfactory to use to break it loose. If the stream still refuses to run, a wooden plug, attached to a long iron bar should be inserted and the ladle lowered against some heavy mold, etc. The weight of the ladle will drive this wooden rod through any obstruction, and is preferred over an iron bar in that any small metal dribble will not freeze against

it. Such a procedure is dangerous, to say the least and often results in a ladle which leaks badly.

A ladle which leaks under the furnace is caused by only one thing—a poor setting of the rod. It may have been that a small piece of dirt has stuck to the nozzle brick, or the stopper head, and the ladle still held sand, but when the pressure of the metal was exerted this accretion moved, opening a small orifice through which the metal easily forces its way. Speed is essential to get over the first mold so that the stream will have a chance to wash away any small hanging particles. After several openings such a leak ordinarily will stop, and furnishes difficulty only in proportion to the amount of the leaking stream.

### *Plug Cracking*

A slight amount of moisture in the graphite stopper head may be the cause of serious trouble, the steam produced under the influence of the metals heat causing the head to split in two. The first opening usually will give a clean shut, but on the second a slight dribble will start, which gradually gets worse as the pouring proceeds until near the end of the pour a bad stream may be leaking from the ladle. As the rod cracks the metal works its way through this crack, gradually enlarging the opening, until often such a heavy stream leaks that it is necessary to tilt the ladle and finish the pour over the lip.

This trouble is more frequent in localities where moisture predominates, in such places as are located in marshy or swampy country, the graphite having a strong tendency to take up a large amount of moisture. The author has seen instances where rods that had been dried thoroughly and allowed to stand over night in a slightly warm oven, have developed head cracks, although the stopper head itself when it was set in the ladle was still warm to the touch. To overcome any further occurrence of this trouble, the rods should be heated on the head

end to a high temperature before being finally set for metal.

One practice adopted to cover this point is as follows. As soon as the rod has been tried in the ladle, and attached to the gooseneck, it is removed from the ladle and hung up on end, so that the graphite plug is in a small coke fire, the red hot coke surrounding the entire head. Its closeness to the hot coke is regulated according to the time to be held in such a position, the main point being the fact that the stopper head itself should be a fair red when finally lifted and set in the ladle preparatory to the pour. A red hot stopper head never will crack. It offers much less chance of splitting or spalling when the hot metal strikes it. The head helps to preheat the nozzle surface aiding in the prevention of stickers, etc. If the heating is not too prolonged there is no chance of oxidizing the surface and spoiling the set. Before setting in the ladle, such a rod should have the head well brushed with a piece of old sack to insure that no dirt or coke is hanging to the surface.

### *Plug Burning On Side*

As a heat is poured the graphite plug burns down considerably, often being reduced a 1/2-inch in length on a hot heat. Occasionally this burning may take place in an irregular manner, one side of the stopper head burning away faster than the other; or a certain spot may give way quickly. The result is that an opening in the head is left through which the metal passes, causing a leaky ladle. Often, this is caused by a soft spot on the head itself, or it may be caused by the head being scratched or chipped during handling. A small leak will grow in size rapidly especially where the metal is hot, and it often becomes unmanageable. This is hard on the pouring man as often he cannot tell what is causing the leak, and proceeds on the assumption that the seat of the

trouble may wash away. By the time the cause appears, the leak may be so bad that considerable metal is lost. A soft head cannot be foreseen, but by taking all possible precautions of examining every rod as made up, minor cracks, chipped spots, and scratches may be seen, and the head scrapped, or used on a heat where there are only a few stops to be made.

It may happen that the joint between the stopper



Fig. 57—When the Plug Becomes Welded to the Nozzle Brick, Breakage Sometimes Results Before the Joint is Released

head and the first sleeve brick becomes loose, allowing the metal to attack the pin which holds the head against the brick. The metal gradually will eat its way through the plug until a clean cut is made. The ladle thus is shut off automatically and must be poured either over the lip, or the plug forced out of the way with a wooden pin and the ladle poured running wide open. This may be caused by the plug in the bottom of the stopped head coming loose allowing the metal gradually to eat through the nut.

As this trouble often occurs at about the end or the middle of the heat, it furnishes a mean proposition to handle.

### *Pin Melting*

On extremely hot heats the writer has seen instances where this small steel pin actually melted away from the heat conducted through the stopper head. The amount of heat to which this pin is exposed is considerable and

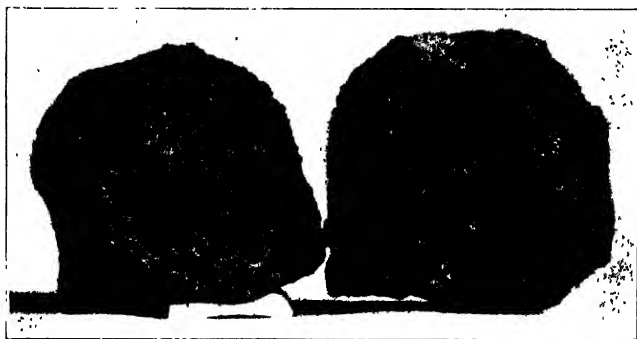


Fig. 58—When a Stopper Plug Breaks Trouble Ensues

quickly will crystallize the steel to such a point that its strength is low. A pin should be used only two or three times, and should be carefully examined for any traces of weakness each time before it is used.

At least 75 per cent of bottom pour ladle trouble is caused by sticking stopper head. The ladle will pour perfectly on the first opening, but when the attempt is made to open up on the second the rod cannot be lifted. This is caused by the graphite head sticking to the nozzle brick. Often this sticking is light, and the stream can be opened by exerting a little force on the pouring lever, but at times the welding is so tight that force will not open the passage. This welding is caused by the cold-

ness of either the metal, or the nozzle brick. On the first opening the amount of metal which passes through the nozzle is not enough to heat it thoroughly, and when the rod is forced into place it forms a light ring of metal between itself and the brick, which immediately begins to solidify. As this metallic ring solidifies it binds the brick and the head tightly. When force is exerted certain things may happen as follows:

If the ring is light, the ladle will open and the stream will pour forth.

The stopper head may be actually pulled in two.

The pin may be pulled through the stopper head.

The joint may be so tight that the nozzle brick is pulled free from the sand, and slips up and down as the lever is worked.

Fig. 57 shows a stopper head sticking to the nozzle brick. This welding was so tight in this particular instance that the brick had to actually be chipped away for purposes of illustration. Fig. 58 shows a stopper head which has pulled in two.

### *Sticking Causes Trouble*

A *sticker* offers peculiar results. The author has seen instances where on the second opening the rod would raise, but no metal would come from the ladle. On inserting a pricker the metal started and the remainder of the heat was poured perfectly, the ladle working in a most excellent manner. Again instances were encountered where the stopper head actually pulled apart, and later welded itself, the heat pouring perfectly. Much depends upon the initial temperature of the metal. If the latter is hot, the heat often will be sufficient to melt away any small obstructions allowing a perfect pour. If the metal is cold the frozen ring may increase offering considerable trouble.

The safest method of avoiding trouble from sticking rods is to have three or four molds ready. The ladle

is opened over one of these and as quickly as possible over the remaining few. This rapid movement is a great aid in preventing tight freezing of the ring, and after the ladle has been opened and shut several times this ring has been melted away, and the nozzle brick has been so heated that the formation of another ring is avoided. For heats where large castings are to be poured with cold metal, a large sized nozzle brick is used allowing a quicker passage of the

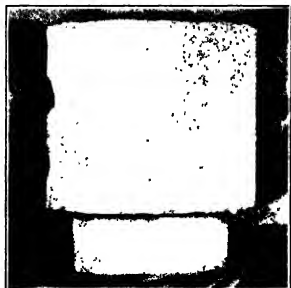


Fig. 59—Nozzle Brick Which Are Notched Resist the Tendency to Lift if the Plug Sticks

metal. If a delay occurs with the ladle after the first opening, trouble will occur, speed being the best possible precaution against a sticker.

The most serious trouble encountered on sticking rods is caused by the nozzle brick loosening in the ladle, and slipping when the rod is raised and lowered. This makes it impossible to pour from the bottom and lip pouring must be followed. As the sides of a nozzle brick are smooth at the best, this slipping is of frequent occurrence unless some counteracting measures are taken. The remedy is to cut deep grooves in the sides of the nozzle



brick before it is set in the ladle bottom. These offer a grip for the sand, and since adopting this remedy the writer never has had a slipping brick. Fig. 59 shows such a brick with the grooving cut.

Frozen nozzles are caused either by the metal being too cold for the size of nozzle used, or by pouring such a small stream that the opening progressively becomes smaller as the metal freezes against the sides until the entire opening is closed and the stream is shut off. If the freezing has been caused by cold metal there is nothing which can be done outside of lip pouring; but if the freezing occurs while the metal still is hot the opening can be burned out by using an ordinary acetylene torch. Any freezing of the nozzle is caused by carelessness as it easily can be seen in advance, when there is plenty of time to go to heavier molds. Its first indication is when small drops from the ladle begin to freeze slightly onto the nozzle ring, requiring the use of a light bar to pry loose. These accretions enlarge until complete closing results.

### *Handling the Ladle*

Assuming that the ladle has been filled with fairly hot metal and is ready for pouring, the first step is to get the ladle centered over the first mold, the nozzle being perfectly centered on the pouring cup. The size and make up of this first mold is important. It should be large enough to take at least 150 to 250 pounds of metal, figuring on a 3 to 4-ton heat in the ladle. It should be a casting with a minimum of cores as it is apt to cut badly. While a large casting is preferable, it never should be used on account of the high temperature of the metal at this time. This first casting should be lined up with several others in case a dribble occurs when the ladle may be quickly placed over the second cup, and then another until a clean shut is assured.

On opening the ladle at first, a fair stream should be

given until at least 100 pounds of metal has poured when the stream should be rapidly shut off. If a clean shut is obtained the casting can be finished and the ladle moved. However, if the nozzle dribbles, due to a little dirt or cold metal being against the head or the nozzle, the rod should be opened and closed several times until this foreign matter is removed. If the mold is filled and the ladle still dribbles, the only thing to do is to get over the next mold as rapidly as possible and repeat this opening and closing. In the majority of cases a clean shut will be obtained on the first opening, but there will be times when a dribble will start which will continue throughout the remainder of the pour.

In pouring steel castings, a fair sized stream always should be used, the smaller castings being poured first when the metal is hottest, tapering off to larger and heavier pieces toward the end of the pour. The author has found good practice to be to pour mostly light work on one heat, and follow with another for the heavier castings. On the hot heats a  $1\frac{1}{2}$ -inch opening is used, while for the large castings where cold metal is used either a 2 or a  $2\frac{1}{2}$ -inch brick is used, depending upon the size of the heat, and the number of stops to be made. In opening and closing the stream considerable practice is required. The opening and closing should be positive, the rod being closed with a quick snap of the wrist which throws the stopper into place, and forces any accumulation of metal from the face of the nozzle brick.

With the trouble often arising from bottom pour ladles causing them to be poured over the lip, it is mandatory that a good system of ladle gearing should be adopted, which will allow the ladle to be tilted easily, and accurately if desired. A good arrangement is that of a helical worm gear, which operates easily in a positive manner, and is self-locking. The tilting arrangement together with the mechanism operating the rod al-

ways should be kept well cleaned and thoroughly greased so that every movement is quick and easy with no possible chance of binding.

With the many excellent ladles placed on the market by the various manufacturers it is not worth while to build one. The different manufacturers have profited by experience in the design of their ladles, the rod operating mechanisms, and the tilting gears, and their product is such that it is hard to improve upon. Home made equipment usually is costly in the end, and the modern and progressive foundry should not be quick to adopt their own design especially if differing radically from a standard equipment. In the purchase of ladles for foundry use, it will be preferable to obtain those which are short and wide, rather than the higher and more narrow. Due to having less head of metal to force the flow into the mold, the easier and softer the stream will be and the better the casting.

#### *Cleaning Costs Added*

Much trouble and cost is caused the cleaning room by careless pouring of steel castings. Scabbing is caused by pouring metal either too hot or too fast into a certain casting; the same cause often gives rise to heavy fins, the force of the heavy stream actually lifting the cope from the drag. Shrink holes are caused by improper heading or by lack of feeding, often resulting in a lost casting due to the lack of a little thought. Large castings where the shrinkage is heavy should be poured slowly until the metal is into the head, when the ladle should be moved over the head and this filled with fresh metal. This places the hot metal where needed, in the point of last solidification, and where it will perform its required duty of feeding the body of the casting. If necessary several additions of hot metal should be made to this head, when it can be covered carefully with a small amount of charcoal and allowed to set.

# XVI

## COST DATA

**P**RESENTATION of cost data covering the production of electric furnace iron and steel for castings is difficult, due to the differing conditions found in various shops and localities. However, certain similarities exist in all operations, and if detailed figures can be obtained covering the specific items mentioned, the results can be changed to cover the situation for any certain set of conditions.

While the final cost of the castings themselves is the most important item for any shop, this is impossible of general discussion, due to the wide differences of castings made. One shop specializes on heavy jobbing work; another on light castings capable of quantity production; while yet another makes small jobbing work only. Therefore, the only figures which will mean anything are those covering the cost of the molten metal in the ladle.

Costs of steel in the ladle will vary directly according to:

- Continuity of operation.
- Process, whether acid or basic.
- Size and make of furnace.
- Class of product being made.
- Cost of power and labor.
- Geographical location.
- Efficiency of operations.

The furnace operating continuously, naturally will make cheaper steel than one running only two or three heats a day, due to the ability always to melt on a hot hearth. This will manifest itself by cheaper power costs, less electrode consumption, less labor cost per ton of metal, greater refractory life, and a much lower figure for fixed costs per ton.

The acid process will be found cheaper than the

basic, due to the shorter length of time required for a heat, the saving in slag materials, and the greater tonnage produced over a certain length of time.

A new modern type of furnace will make cheaper steel than an old antiquated one. The larger furnace will make cheaper metal, due to the greater tonnages produced, and the greater efficiency obtained from melting larger units of metal at one time.

The shop making the smaller sizes of work, will require hotter metal than the shop making large, heavy castings, causing a rise in the costs of metal by increasing the figures for conversion.

Costs of power and labor vary greatly in different localities giving rise to great differences in the cost of manufacture.

The geographical location of the shop is important on account of the freight charges for materials. Certain articles necessary for the electric furnace are made only in the eastern part of the country, as for instance, the following: Ferroalloys, electrodes, certain classes of refractories, stopper heads, etc. Naturally, the shop in the South or the far West is at a disadvantage in the cost of such necessities.

The efficiency of operation is by far the most important point of the lot. The author has seen shops having a preference in costs lose out time after time on bidding for a certain job, merely on account of the greater operating efficiency in the less favored concern. This efficiency of operation manifests itself in many ways. An efficient shop has fewer lost castings, due to better quality of metal and more careful floor work. It has less unnecessary heating of the metal for a certain heat and produces a greater tonnage per man per month. All of these are points directly traceable to the quality of supervision, and amount to a considerable figure at the end of a year. To the new shop starting on an electric furnace career,

one suggestion is offered. Obtain the services of the best man it is possible to get. A man worth ten thousand dollars a year will save his salary many times over, and will prove to be a big asset, while a cheap man will prove dear at any price.

Estimated costs of metal made in certain types of electric furnace, often are put out by the manufacturers of the furnace. Such figures are made up for a set of special results or conditions impossible to obtain under the average shops operation. In the data on specific costs which follow, the author has attempted to pick out various cases differing sufficiently so that a parallel may be drawn for shops operating under almost any set of conditions. Consequently, costs covering lengthy periods of time have been chosen that the law of averages may operate and give figures of actual worth. Instances given have been taken from actual operating figures, and the many details are included as far as is possible.

#### Example No. 1

This shop is located on the Pacific coast, and is operating a 6-ton Heroult furnace on a basic hearth. The operations continue over the entire 24 hours, the product being large sized work, requiring rather low temperatures to pour. The two slag process is used, the scrap being rather high in phosphorus and sulphur. Heats are poured after holding under a carbide slag for approximately 45 minutes.

Power is obtained at a flat energy rate of 1 cent per kilowatt hour, with no demand, which constitutes a low figure. Labor was at this time rather high, first helpers being paid 77 cents per hour, while common labor costs 59 cents per hour. Three men were on the furnace, one handling the ladles, and pouring the steel, while four laborers were used to charge the furnace.

It will be observed from the following costs of ma-

terials that some items, due to the high freight rates, are abnormal.

Electrodes cost 9 cents per pound, laid down at the furnace.

Lime, 1.21 cents per pound.

Fluorspar, 85 per cent, 1.59 cents, pound.

Coke, crushed, 1.26 cents, pound.

Ferromanganese, 9.23 cents, pound.

Ferrosilicon, 50 per cent, 3.95 cents, pound.

Magnesite and refractories were purchased locally at standard figures.

Conversion Cost	
Labor:	
3 first helpers, 3 ladlemen, 3 helpers, 12 laborers, to charge \$ 2.09	
Power:	
575 kilowatt hour per ton . . . . .	5.75
Repairs and renewals:	
Brick, patching, and electrodes .. . . .	3.60
Slag materials.	
Lime, 79.5 pounds per ton .. . . .	0.96
Spar, 12.1 pounds per ton . . . . .	0.19
Coke, 7.1 pounds per ton . . . . .	0.105
Alloys:	
Ferromanganese, 9.8 pounds ton . . . . .	0.905
Ferrosilicon, 8.9 pounds per ton .... .	0.355
Scrap:	
\$16.40 per net ton @ 2.53 per cent loss . . . . .	16.80
Supervision and fixed charges .. . . .	2.30

Total per net ton of metal in the ladle .. . . . \$33.055

This furnace poured on the average 5.5 heats of 7.0 tons each in 24 hours, or approximately 1000 tons per month. The figures covered the six months run from April to September, 1921, prices being those in effect at that time.

#### Example No. 2

The data in this example cover the comparative operation of a 6-ton Heroult furnace, basic lined, in opposition to a 20-ton, open-hearth furnace, acid process. The figures are for a four months' period, during 1920, and are those covering actual operations as observed by E. H. Ballard, General Electric Co., Schenectady, and reported by him in a paper prepared for the American Foundrymen's association. The electric furnace was operated during the day only, two heats being poured in this time, approximating 310 tons of metal per month, the steel

Table XLV

ELECTRIC FURNACE COSTS		Cost per net ton	
Per cent charged	Item	Price	
1.00	Pig iron .....	\$51.00 G. T.	\$0.46
20.13	Shop returns .....	18.00 G. T. }	
1.64	Defective castings .....	18.00 G. T. }	3.50
15.63	Miscellaneous scrap .....	21.25 G. T.	2.97
0.49	Nickel turnings .....	21.50 G. T.	0.09
58.71	Steel turnings .....	8.50 G. T.	4.45
0.55	Nickel Accumulations .....	21.50 G. T.	0.11
0.60	Iron borings .....	12.00 G. T.	0.06
98.75	.....	12.80	11.64
Special metals:			
0.54	Ferrosilicon .....	155.00 G. T.	0.74
0.37	Ferromanganese .....	225.00 G. T.	0.74
0.09	Wash metal .....	71.20 G. T.	0.06
0.07	Aluminum-Titanium .....	166.90 G. T.	0.12
0.04	Nickel .....	0.50 lb.	0.38
0.06	Copper .....	20.16 100 lbs.	0.23
0.08	Iron ore .....	9.16 G. T.	0.01
1.25	.....	204.38 G. T.	2.28
100.00	Total metals charged .....	15.59 G. T.	13.92
Molten metal cost:			
	Cost of metals .....		13.92
	Direct labor .....		2.00
	Items of expense .....		21.58
	(per detail below)		
100.00	Total cost of melt.....		27.50
8.00	Shrinkage .....		
92.00	Cost of metal in ladle .....		40.52
30.90	Credit—scrap produced .....	\$ 16.16 N. T.	
61.10	Good castings produced .....		53.06
Summary of expense:			
	Electrodes, 30 pounds per net ton		
	0.08 pound .....		2.52
	Current, 720 kilowatt hour per ton		
	1.25c kilowatt .....		9.05
	Oil for ladle, 0.079 gallon .....		0.26
	Water .....		0.24
Slagging and patching:			
	Sand, lime, spar, coke, carbon, syndolag .....		1.80
	Ladle repairs .....		1.43
	Furnace repairs .....		1.27
	Royalty (44.6c per net ton output)		0.27
	Depreciation 10 per cent .....		1.14
	Expense—labor .....		1.30
	Expense—all other .....		3.30
Total melting expense .....			\$ 21.58
Heats poured 131.			
Average weight per heat, 13,918 pounds.			
Cost data cover 912 tons produced.			



being poured into a miscellaneous assortment of work. The costs are given in Table XLV.

On analyzing these costs certain items are found which under different conditions could be changed: The cost of nickel and copper from special metals may be omitted, giving a reduction of \$0.49 per ton. The large loss of 8 per cent probably was due to the great proportion of borings used, and should not be charged against the expense covering special metals. By using the one slag process a reasonable saving should be effected in the cost of slag making materials, with probably a slightly lower power, electrode and refractory consumption.

The figures from the open hearth operating over the same period are as follows:

MOLTEN METAL COST—Per net ton

Cost of metals . . . . .	\$22.70
Direct labor . . . . .	0.83
Items of expense . . . . .	9.95
Total cost of melt . . . . .	\$33.48

However, the percentage of good castings from this process was only 56.34 per cent so that the cost of the steel in the castings amounted to \$49.24 per net ton, or only \$3.82 per net ton less than that from the electric furnace.

Considering the extra quality from the electric furnace, and the fact that this shop is located close to the heart of the pig iron country, these figures are favorable for the cost of the metal from the electric furnace. The difference easily could be changed the other way by a shop further removed from the source of its pig iron, the freight charges rising as the distance increased.

*Comparison of Acid and Basic Cost*

The cost data in Table XLVI covers the operation of a three-ton furnace made by the Pittsburgh Electric Furnace Corp., Pittsburgh, operating on the acid hearth, making small sized steel castings. The figures given cover the operation for the month of October 1920. The con-

ditions cover the production of approximately 600 tons of steel, and the furnace averages about 7½, three-ton heats per day of 12 hours.

Further figures from the same shop covering the cost per ton over a six months run are as follows:

Metals .....	\$19.77
Electrodes .....	1.53
Power .....	10.36
Miscellaneous .....	0.25
Labor .....	3.35
Repairs .....	1.27

Table XLVI

\$36.53

## COST OF ELECTRICALLY MELTED STEEL PRODUCED ON ACID HEARTH

	Pounds	Price per ton	Total cost
Material charged .....			
Clippings .....	234,301	\$28.23	\$ 2,952.66
Heavy drop forge .....	167,247	28.95	2,161.50
Turnings .....	207,897	18.00	1,673.57
Shop scrap .....	561,796	25.06	6,284.81
Spiegel 40 per cent .....	24,324	67.50	732.88
Silicon 50 per cent .....	5,495	85.00	208.48
Iron ore .....	2,760	9.11	11.22
Aluminum .....	60	0.338 lb.	20.28
Total .....	1,203,880		\$14,045.40
Average per net ton .....			\$24.55

## Cost per ton of metal in ladle

Metals .....	\$24.55
Electrodes .....	0.77
Power .....	12.03
Miscellaneous .....	0.34
Labor .....	2 40
Repairs .....	0.75

From THE FOUNDRY of April 15, 1921. \$40.84

Another acid furnace shop operating near Pittsburgh on a three-ton unit of the same type shows a melt cost over several months operation of \$35.20 per ton of metal in the ladle. This figure was taken from the operation during a 16-hour period, making small to medium size castings mainly for railroad use.

*Costs In Southern Shop*

The data in Table XLVII covers the operation of a three-ton furnace from January 1923 to December 1924.

This furnace made small to medium size castings, principally for railroad car construction. The average number of gates poured per heat was 45, so that it may be seen that the metal was heated to a rather high temperature. The practice was of high degree as the losses were kept to a minimum.

The costs have been segregated according to the tonnages melted for the various months. The average cost was close to that shown under 300 tons.

The general overhead, including all fixed charges and

Table XLVII

COST PER TON DECREASES WITH INCREASE OF METAL MELTED

Item	Metal charged		
	200 tons	300 tons	400 tons
Labor .....	\$ 2.18	\$ 1.73	\$ 1.52
Power .....	15.00	11.50	10.25
Electrodes .....	1.20	1.02	0.84
Refractories .....	0.60	0.45	0.30
Tools, water .....	0.25	0.20	0.15
Ladles .....	0.25	0.25	0.25
Alloys .....	1.23	1.23	1.23
Miscellaneous .....	1.00	0.80	0.60
Metal .....	18.90	18.90	18.90
Total .....	\$40.61	\$36.08	\$34.04

Note the drop in the costs of conversion as the tonnage increases, from \$20.48 for 200 tons; to \$15.15 for 300 tons; and to \$13.31 for 400 tons.

supervision, ran from \$30.80 a ton of finished castings on the basis of 200 tons charged, down to \$20.25 for 300 tons, and \$15.40 for 400 tons. The return in cleaned castings was slightly over 65 per cent of the metal charged. When all these figures are totaled on the basis of finished work, the difference of tonnage is much more apparent. The costs for the steel in the completed casting are \$87.60 per ton for 200 tons; \$70.15 for 300 tons; and \$62.10 for 400 tons.

#### *Costs of Electric Furnace Iron*

The following cost data cover the results obtained by

the author on the manufacture of synthetic pig iron. The figures are those obtained on the Pacific coast during 1921. A six-ton acid lined furnace was used, and poured 45 tons per daily run. The figures follow:

	Per net ton
Labor . . . . .	\$ 0.666
Power 525 kilowatt @ 1c . . . . .	5.250
Electrodes 20 pounds . . . . .	1.600
Repairs . . . . .	0.500
Recarbonizer . . . . .	0.300
Alloys: Manganese 0.50% . . . . .	
Silicon 2.00% . . . . .	4.000
Scrap: Borings at \$5.00 per ton, 3% loss . . . . .	5.150
	<hr/>
	\$17.7160
Miscellaneous at 10% . . . . .	1.7716
	<hr/>
Total . . . . .	\$19.4876

The pig iron made was standard foundry iron to be

Table XLVIII

COST OF SYNTHETIC PIG IRON PRODUCED ON THE BASIC HEARTH

Item	Cost per day	Cost per net ton
Labor:		
3 melters @ 85c . . . . .	\$20.40	
3 first helpers @ 81c . . . . .	19.44	
3 helpers @ 67c . . . . .	16.08	
3 cranemen @ 81c . . . . .	19.14	
3 ladlemen @ 77c . . . . .	18.18	
3 floormen @ 67c . . . . .	16.08	
6 laborers @ 62c . . . . .	29.76	
	\$139.38	\$ 3.871
Power:		
18,000 kilowatt hours @ 1c . . . . .	\$180.00	\$ 5.000
Repairs and renewals:		
Brick, electrodes, patching . . . . .	\$121.20	\$ 3.370
Alloys:		
Manganese @ 1.00 per cent . . . . .	48.60	
Silicon @ 2.00 per cent . . . . .	115.20	
Carbon @ 3.00 per cent . . . . .	12.00	
	\$175.80	\$ 4.883
Miscellaneous:		
Lime, sand, spar . . . . .	\$ 18.00	\$ 0.500
Scrap metal:		
Mixed borings @ \$3.50 . . . . .	\$126.00	\$ 3.500
Fixed charges: . . . . .	\$ 58.00	\$ 1.610
	<hr/>	<hr/>
Total cost . . . . .	\$818.00	\$22.734

used for castings requiring little machining, or none at all.

### *Basic Synthetic Iron*

Actual costs taken from the operation of a six-ton basic furnace making special pig iron from steel scrap are given in Table XLVIII. The iron was intended for use

Table XLIX  
OPERATING COSTS OF A 3-TON FURNACE

Item	Cost per day	Cost per ton
Furnace Labor:		
3 melters @ \$6.00 .. . . . . .		
3 helpers @ \$4.00 .. . . . . .	\$30.00	\$ 1.00
Floor labor:		
3 cranemen @ \$5.00 .. . . . . .		
3 helpers @ \$3.20 .. . . . . .	\$24.60	\$ 0.82
Supervision @ \$10,000 per year .. . . .		\$ 1.11
Total labor cost .. . . . . .		\$ 2.93
Power: 600 kilowatt hours @ 1c .. . . .		\$ 6.00
Electrodes: 20 pounds @ 8c .. . . . . .		\$ 1.60
Repairs .. . . . . .		\$ 0.50
Alloys: Manganese @ 1.00 per cent .. . . .		
Silicon @ 2.00 per cent .. . . . . .		
Carbon @ 3.00 per cent .. . . . . .		\$ 4.87
Ladles and miscellaneous: .. . . . . .		\$ 0.25
Conversion cost .. . . . . .		\$16.15
Scrap: covering losses, etc. .. . . . . .		\$10.00
Depreciation, etc. .. . . . . .		\$ 0.83
Brokerage on selling: (Optional) .. . . .		\$ 1.00
Total manufacturing cost .. . . . . .		\$27.98
Emergency: 10 per cent of cost. .. . . .		\$ 2.79
Absolute maximum cost .. . . . . .		\$30.77

in a cupola making medium hard castings The output was 36 tons per day.

In these particular costs the labor is far too high, and the cost of metal is exceedingly low. Considering these items and such points as loss in melting, handling and floor materials, the cost would probably be closer to \$20 per net ton. As pig iron at this particular time cost \$45 per net ton there was quite a saving made by this operation.

Table L

## COST OF ELECTRICALLY MELTED GRAY IRON PRODUCED FROM SCRAP IRON

Item	Cost per ton
No. 1 scrap 8% loss @ \$45.00 ton.....	\$48.60
Limestone 50 pounds per ton @ \$4.00.....	0.10
Fluorspar 6 pounds per ton @ \$25.00....	0.075
Carburizer: Coke, coal, ground electrodes.....	0.60
Ferromanganese 8 pounds per ton 5c pound..	0.40
Ferrosilicon 60 pounds per ton 5c pound.....	3.00
Power, cold melt 450 kilowatt hour 1½c.....	6.75
Electrodes 15 pounds graphite per ton.....	3.45
Linings:	
Walls .....	0.30
Hearth .....	0.20
Roof .....	0.30
Lining repairs:	
Banking repairs .....	0.35
Roof patching .....	0.15
Spout and slag doors.. ..	0.20
Ladle lining... ..	0.20
Ladle drying .....	0.30
Furnace tools .....	0.25
Labor:	
Metallurgist and superintendent 30% of time at \$500 a month.....	0.833
Head melter, two at \$8.00 per day .....	0.60
Helper, four at \$4.50 per day.....	0.90
Furnace floor labor, two at 40c hour.....	0.32
Ladle pit labor, two at 40c hour.....	0.32
Ladle liner, two at 50c hour for 8 hours.....	0.40
Scrapyard labor, two at 40c for 8 hours.....	0.32
Shop labor .....	0.25
Chemist and laboratory supplies \$200 and \$50 per month .....	0.416
Unproductive payroll .....	0.10
Depreciation furnace equipment at 10%.....	0.582
Amortize furnace investment in 10 years.....	0.582
Interest at 7 per cent a year.....	0.408
Insurance .....	0.09
<b>TOTAL PER NET TON.....</b>	<b>\$71.35</b>

Based upon 500 tons monthly.

In Table XLIX, the figures for the cost are taken from a shop that produced synthetic iron at a rate of 30 tons per day.

Costs using 3-ton furnace made by the Ludlum Electric Furnace Corp., Watervliet, N. Y., for making iron for machined castings are as follows:

Item	Cost per ton
Power: 575 kilowatt hour @ 2c .....	\$11.50
Electrodes: 10 pounds @ 25c .....	2.50
Ferrosilicon: 30 pounds @ 4c .....	1.20
Coke: Refuse from cupola size .....	0.75
Slag materials: lime, sand, spar and carbon dust .....	0.50
Cooling water and tools: .....	0.15
Refractories: .....	1.00
Labor: Melter @ \$9.00 day	
Laborers @ \$3.12 .....	2.50
Yard labor and charging: .....	0.50
Direct supervision: 50% of labor .....	1.50
Fixed charges: .....	2.52
	<hr/> \$24.62

This cost per ton is the total less the cost of metal, which figuring cast iron scrap at \$18 with a 5 per cent loss, would bring the total cost up to \$43.52 with an actual cost of conversion of \$14.25 per ton. These figures were obtained on the basic furnaces operating three heats or nine tons per day, the product being a high grade, low sulphur iron, capable of being used for any purpose.

R. C. Gosrow gave figures in Table L. They are taken from THE FOUNDRY of March 15, 1921, and relate to the cost of synthetic gray iron.

In the same article the cost of producing the same grade of iron from steel by building up the carbon and silicon is given. The outstanding feature is the difference in costs of the metals charged. The cost of steel being less than half of that for scrap iron. These figures are as follows:

#### COST OF ELECTRICALLY MELTED GRAY IRON PRODUCED FROM STEEL

Steel turnings	
Shear scrap	
Forge flashings	Cost per
Stamping scrap	net ton
averaging \$19.00 @ 10% loss .....	\$20.90
Fluxes, etc. ....	0.20
Carburizer (gas carbon) .....	0.70
Spiegel 45 pounds at 1.75c pound .....	0.70
Ferrosilicon 85 pounds ton .....	3.80
Power 450 kilowatt hours at 1½c.....	6.75
Electrodes 15 pounds graphite .....	3.45

Linings .....	0.40
Lining repairs .....	0.40
Ladle repairs .....	0.20
Ladle heating .....	0.25
Furnace tools .....	0.25
Labor, chargeable to furnace and production.....	3.85
Fixed charge .....	1.00
	<hr/>
	\$42.85

From the foregoing data on actual costs some idea may be obtained of the differences due to varying conditions, and while they can be of no direct value, the figures given may be changed to accord with present day costs and location, that some value may accrue from their presentation.



# APPENDIX

TABLE 1

## LOG OF BOTTOM BURNING BASIC LINING

### Six-Ton Heroult Furnace

Furnace bricked up with flat bottom, two courses of clay and two courses of magnesite brick. Dead corners rammed in with a mixture of four parts of magnesite to one of basic open-hearth slag, using tar as a binder. This mixture rammed up along walls as high as possible to tend to prevent spalling of the magnesite brick during heating up. Electrodes set "star" with joint heavily sealed with electrode chips and compound. Set up placed on seven and a half inches of magnesite brick, well cemented into place.

Furnace heated up to a good hot temperature by means of two oil torches inserted through the charging doors.

The electrodes were removed from furnace and complete hearth examined. A bar run against hearth showed it to be hard. The bottom was 12 inches deep in the center. The total elapsed time the current was on was 19 hours. Delays outside of shut down consumed 1 hour. The power consumption was 10,800 kilowatt hours.

This hearth went over 2000 heats before being removed to change furnace over to acid operation. On removal perfect burning was shown to have been accomplished clear through to the brick.

### FIRST DAY

4:30 p. m.

Current on at 2000 amperes, drawing a load of approximately 500 kilowatts. Arc irregular but holding well.

5:30

Current raised to 3000 amperes drawing a load of 700 kilowatts. Slight amount of spalling especially in front of door openings. Raked these pieces of brick out with fettling spoon.

6:30

Current raised to 4000 amperes, 900 kilowatts. Furnace slowly heating up. Spalling ceased.

7:30

Center plug slipped breaking contact. Set two loose electrode screws along side joint giving new connection. Furnace at a fair red heat. Tar burning out of rammed corners. Steam still coming from bottom vent holes.

8:05

Current on at 900 kilowatts. When electrodes were lowered one was allowed to strike setup breaking electrodes apart, but due to good luck it slipped back into place when pressure was removed.

9:45

First addition of refractory material made consisting of a mixture of magnesite four and ground slag one part. Four shovelfuls carefully scattered over entire hearth. Current raised to 1200 kilowatts to overcome cooling caused by this addition.

10:10

Silica brick running slightly, but not enough to cause any danger. Tests taken from four quarters of hearth all show good sintering. Another quantity of the same four to one mixture added, about 100 pounds, thrown around the hearth edge.

From this time up to 1:00 a. m. additions were made at intervals of approximately 30 minutes. Tests were taken before each addition from in front of each of the three doors, between each door, and from behind the center electrode, making six tests on each trial. Constant adjustment of the mixture was required to give proper sintering conditions, using either more slag or magnesite to balance. The

setup by this time had become badly burned at the joint and was arcing with sufficient strength to form a molten area about a foot in diameter in the center of the hearth, and about 2 inches in depth. The arc was of such violence that the carbon was rapidly reducing the magnesite with which it was in contact, and the gas was so strong that nothing could be seen when the doors were opened

#### SECOND DAY

1:00 a. m.

Shut off current and removed electrode stubs from furnace. As soon as furnace had cooled sufficiently for a man to enter it was carefully examined. In the center where the carbon had fallen into the magnesite there was a bad patch where the magnesite had been reduced. This was dug out for a depth of about 1 inch. Along the walls the silica brick had run slightly requiring a small amount of chipping to clear this accretion. Remainder of hearth was in excellent condition being extremely well burned and hard.

Another similar setup made, placed on five and one-half inches of magnesite brick

5:10 p. m.

Current again on at 500 kilowatts.

6:10

Current increased to 600 kilowatts. Furnace warming slightly with no evidence of spalling.

7:10

Raised to 750 kilowatts

8:10

Increased to 900 kilowatts. Furnace becoming hot, but a test did not show any evidence of sintering

8:30

Test shows evidence of pastiness from the six test positions. Three scoops of a mixture of magnesite six and slag one thrown in directly behind the center electrode where a hot spot was developing, due to arc flaring against wall. Walls glistening slightly, but no signs of running.

8:35

Due to carelessness of helper electrode was allowed to strike setup while lowering, causing setup to break apart. Bars were put into furnace and the setup was pried back into its regular position. A magnesite brick was placed alongside of each electrode to hold it in position and prevent any further tendency to roll out of place.

9:00

Current on again, new setup working fine and holding current with no signs of arc at joint. Current running at 900 kilowatts.

9:40

Current cut to 700 kilowatts. Additions of the six to one mixture again started, being made approximately every 30 minutes. Test showing perfect sintering, although constant adjustment is required

10:30

Current cut to 600 kilowatts. Walls beginning to assume bowl shape. Spout beginning to form nicely

11:40

Current again cut to 500 kilowatts to prevent walls running. From this point on the mixture was cut down to about 10 of magnesite to one of slag and moistened. Spoon used on all additions and mixture placed up along walls to form bowl. Center of hearth is now of sufficient depth. Spout shaping out as far as tapping door. All additions now being made without shutting off the current

#### THIRD DAY

8:00 a. m.

Final addition made along walls, complete hearth being given a light dusting of slag.

8:40

Complete hearth appears molten due to the slag running. Shape perfect. Spout finished. Current shut off and furnace allowed to free itself of gaseous vapor. Electrodes pulled up on walls and slight depressions under each filled with a six to one mixture well rabbled in, to give hearth final rounded shape.

TABLE 2  
LOG OF BOTTOM BURNING BASIC LINING

Three-Ton Heroult Furnace

Electrodes were arranged on bottom brick in the form of a star, elevated on 5 inches of magnesite brick. A plug was set on top of three stubs and carefully cemented in place with electrode compound.

FIRST DAY

8:00 a. m.

Current on low voltage side of transformer drawing approximately 1000 amperes at 90 volts. Bottom of furnace dusted slightly with powdered open-hearth slag. Current gradually raised at intervals until a load of 3000 amperes was being taken. Heating continued until 2:00 p. m. when furnace was hot and slag had been running freely for about 15 minutes.

2:00

Doors opened and electrodes raised and about 5 shovels of straight magnesite thrown in center of furnace and around electrodes, mainly to cool them a little.

2:30

After this first addition had sintered into place another light touch was given around the rim of bottom especially where the arc was striking freely.

3:15

About 200 pounds of magnesite again added being distributed in a uniform manner over the hearth

4:00

Perfect sintering being obtained up to this point. Furnace shut down until next morning. About 3200 kilowatt hours had been consumed up to this time. All door and electrode openings carefully luted with clay to retain as much heat as possible.

SECOND DAY

8:00 a. m.

Temperature of furnace still a fair red, probably about 1400 degrees. Current on low voltage at 3000 amperes. Furnace rapidly heating under arc.

9:00

Center of furnace under arc getting rather hot. Two shovels of magnesite thrown in around stub to cool off hot spots.

9:15

Four full scoops of magnesite spread over entire hearth. Furnace extremely hot and sintering proceeding nicely.

10 00

Voltage changed over to high side—120 to 130 volts, amperes cut to 2000

11:00

Charged four full scoops of a mixture of magnesite two and slag one part around banks of furnace. Sintering proceeding well

TABLE 3  
LOG OF BOTTOM BURNING BASIC LINING

Three-Ton Pittsburgh Furnace

Due to the rounded shape of the hearth of this furnace, the bricking up of the hearth was simple. Two courses of fire brick were laid next to the shell, followed by magnesite brick two high. The side walls in this furnace were laid completely to the roof with a metal encased magnesite brick. The hearth was stepped up so that all that was required was to burn in a layer of hearth approximately seven inches thick in the center and tapering off to about three inches up along the banks.

The setup was laid in the form of a T so arranged that the bottom of the T was parallel with the door openings. Electrodes were set on  $7\frac{1}{2}$  inches of magnesite brick.

FIRST DAY

7:00 p. m.

Current on low voltage side of transformer drawing about 140 volts, with amperes cut down as low as possible. Preliminary to turning on power, furnace had been thoroughly dried and heated with two oil torches. Due to high voltage, arc was irregular for the first 15 or 20 minutes until a red spot had been heated on the setup under each electrode. This heating continued with a gradual increase of the amperes up to 4000.

11:00

Furnace smoking hot, walls beginning to drip slightly. Light touch of magnesite around banks with a small amount of acid open hearth slag in the center of the furnace.

12:00

First large addition of magnesite mixed with acid slag in the proportion of approximately 20 to 1 the slag being powdered and the magnesite wheat size.

SECOND DAY

From this point on additions were made about every half hour, depending on the character of the tests as taken by a small chisel spoon. Great care had to be exercised regarding the acid slag, only enough slag being used to aid in holding the magnesite. This required constant adjustment.

4:00 a. m.

From this time on all material moistened and placed in position with a spoon. Some trouble was experienced in obtaining a good shape behind the head of the T, but this was accomplished by taking plenty of time and dropping the mixture high up on the wall from which position it naturally dropped into its proper position.

8:30

Hearth finished and furnace ready for steel.

TABLE 4  
LOG OF BOTTOM BURNING ACID LINING

Six-Ton Heroult Furnace

Hearth was stepped up using the best grade of silica brick obtainable. The electrodes were set in a V with apex under the center electrode of furnace, raised up 5 inches above bottom by placing on silica brick two high. Brick cemented into place with a mixture of sand and sodium silicate, some sodium silicate being also used to cement the electrodes to the brick. Furnace thoroughly dried out with oil torches and heated up to a low red.

2:00 p m.

Current on low voltage side of transformer drawing 2000 amperes at 100 volts

3:00

Current raised to 4000 amperes. As a slight running of the walls or roof is immaterial in an acid furnace it is allowable to heat up much faster than on basic practice. With no magnesite brick in the furnace there is small likelihood of spalling occurring in any great amount.

4:00

Furnace up to a good red heat. Current off for about 5 minutes while a few brick stubs from roof were raked out of furnace with a spoon.

5:00

Furnace smoking and roof beginning to drip. Current cut to 3000 amperes and first addition of patching made. This consisted of two parts, one of about 200 pounds of clear sand thrown high on the banks to neutralize any drippings from the side walls. The second consisted of 10 of sand to 1 of fire clay spread over the entire hearth.

6:00

About 1 inch of 10 to 1 mixture spread over entire hearth, and placed as high on the banks as was possible.

Examination of furnace while current was off showed slight running of the roof and rather heavy running of walls opposite the arcs. Several shovels of straight sand thrown over each of these spots.

7:00

Current being held from 2000 to 3000 amperes. Tests taken show fair sintering in spots, unburned areas in others. Where sand had not sintered, added a richer mixture consisting of 8 sand to 1 of clay, dusted on lightly. Burning excellent in hearth proper and on areas in vicinity of arcs. Worst unburned areas were in front of doors and pouring spout.

7:30

Tests taken and more sand added where needed. Burning progressing nicely. Depth of burned sand in hearth about 2 inches as shown by test rod, and walls assuming rounded shape. Corners of bucks still showing slightly on stepped up banks.

7:45

Another heavy addition of 10 to 1 made all over hearth and walls, 8 to 1 being used in front of doors and to shape pouring spout. Bar shoved into hearth shows pasty for about  $\frac{1}{4}$  inch with a hard under surface.

8:30

Further patching made, but mixture changed to 14 to 1 and current raised to 4000 amperes.

Tapping spout built up from front of furnace using a long handled shovel, sand being moistened with a solution of sodium silicate in water, about half and half.

9:15

Final additions made with spoon, principally along the banks, sand being well soaked with water.

9:45

Final tests taken from all points of hearth show fine sintering. Light dusting of pure sand, probably  $\frac{1}{2}$  inch thick made with spoon. Current raised to 6000 amperes allowing furnace to drip.

10:30

Current off, electrodes knocked out of hearth and holes filled with 10 to 1 mixture well rabbled in. Electrodes lowered and doors closed and furnace allowed to soak.

12:00

Stubs removed from furnace and ready for steel. Hearth in center 5 inches deep, tapering to a 2-inch thickness near top of banks.

Due to a shortage of acid scrap occurring this hearth was taken out after several hundred heats. Upon examination a perfect burning in was shown, the burned in sand being in one hard, monolithic layer firmly welded into the bricks, and requiring sledge hammers to break it out.

TABLE 5  
LOG OF BOTTOM BURNING ACID LINING  
Six-Ton Heroult

Due to a mistake this hearth was built with straight sides instead of being stepped off, and serves as an excellent comparison with the preceding log. The bottom setup was raised 5 inches and cemented into place, but a star arrangement was used. Before burning was started the dead corners were rammed in with sand mixed with glutin, so that the depth from the corner to the surface was probably 10 inches, this being as an aid in forming the curve.

Furnace brick work was dried out with three gas flames inserted through each door for about 8 hours. Furnace was a fair red when current was first thrown on.

#### FIRST DAY

8:00 a. m.

Current on at 2000 amperes and 100 volts.

9:00

Raised to 3000 amperes, few pieces of brick being taken from furnace.

10:00

Furnace beginning to smoke

11:00

First addition, straight sand being thrown around center setup, about 1 inch in depth.

12:00

Addition made of 12 of sand to 1 of clay over entire furnace. Additions made about every 45 minutes with constant tests. Progressing nicely until 6:00 p. m.

6:00 p. m.

Stub connecting three electrodes slipped breaking contact and causing arc to dig into hearth. Slid back into place, and two electrode nipples placed along each side of pile of sand. This helped to strengthen setup which held well when current was again turned on. Several shovels of sand thrown in where the arc had struck.

7:00

Current again on. Furnace had cooled down considerably so amperes were raised to 5000.

8:00

Current cut back to 3000 and another addition made.

#### SECOND DAY

Additions made at intervals until 2:00 a. m.

2:00 a. m.

Current off, electrodes raked out, and furnace ready for steel.

This hearth was placed in operation in 1920, and is still in use over 12,000 tons of casting steel having been made with no trouble whatsoever.

TABLE 6  
LOG OF BOTTOM BURNING ACID LINING

Three Ton 'Lectromelt Furnace

Two courses of clay brick were laid next to the shell, being mudded into place between the hearth connections, which were sheet iron strips set at regular intervals over the bottom. After the clay brick had set these strips were flattened down and two coats of thin clay slurry swept over to fill the cracks between, and bond the brick together.

In making the mixture for this hearth, a patented refractory cement was used exclusively. Although the cost of this mixture was rather high the furnace was installed to operate under severe conditions, and it was thought that the best possible hearth construction would be the cheapest in the end. This hearth was in steady operation for over a year with absolutely no trouble from the bottom.

As the furnace was placed in operation before the sand mill had been installed, it was necessary to mix all refractories by hand. Three wheelbarrows of the silica sand were mixed at a time, the high temperature cement being made into a thin slurry, and mixed with the sand until a handful squeezed would just bond itself, similar to a properly prepared molding sand. As soon as one batch of this sand was prepared, a section of the hearth along one side was painted with the cement slurry, and the sand immediately shoveled in over this spot. An air rammer was used to ram in the refractory, the hearth being rammed as hard as possible. This operation was continued until the entire hearth had received a layer approximately 1 inch thick.

The bottom gradually was built up in this manner until about 15 inches thick in the center, leaving a hearth of approximately 5 tons capacity. After ramming was completed the bottom was as hard as the silica brick wall. A mixture of sand and sodium silicate then was made, the furnace tilted over as far as possible, and this mixture laid up along the side walls to the roof, both on the front and back walls. All rammed materials then were given a coat of sodium silicate and allowed to stand for about half an hour.

After the roof was set and cemented in place, a small wood fire was started in the center of the hearth. This was lighted about 1:00 p. m. and allowed to burn slowly for two hours.

FIRST DAY

3:00 p. m.

Fire slightly increased, several large pieces of heavy timber being added. Roof and walls rapidly drying out and heavy stream of steam issuing from around doors and roof.

4:00

Steam gradually dying down and a good bed of coals building up over hearth. Fire kept going steadily until a roaring flame was produced.

5:00

Side shell of furnace getting warm, especially around roof ring. Roof gradually taking up expansion and becoming hot. This fire kept going steadily until 8:00 when about two inches of coke was spread evenly over the hearth, and the doors opened slightly to allow an entrance of air into the furnace sufficient to support combustion. When this had become ignited thoroughly another light layer was added. This was continued until the bottom shell of the furnace was so hot the hand could not be held against it. In about another hour the entire shell was in this high temperature condition.

SECOND DAY

6:00 a. m.

Electrodes lowered and arc struck. Low voltage side of transformer used, and gradually raised to 4000 amperes as soon as furnace would take the load.

7:00

Bed of coke white hot, and edges of door jambs slightly glistening.

8:00

Jambs beginning to run. Current shut off and furnace allowed to soak until 8:30 when current was again turned on.



9:00

Shut down for 15 minutes, then on for 15 minutes. This operation continued until 10:00 when power was finally turned off and hearth was ready for steel.

Electrodes were raised and hearth cleaned out with hoes and rattle bars when the furnace was immediately charged for the first heat. The actual amount of power used in the burning operation was 1000 kilowatt hours.

TABLE 7

## LOG OF BOTTOM BURNING ACID LINING

## Two Ton Greene Furnace

One layer of clay brick was laid on the flat over the bottom shell, and the walls bricked up. The hearth was built of a good grade silica sand mixed with giutrin as a binder, the bricks being well painted with the cement before the sand was rammed.

The hearth was built to a depth of 10 inches in the center, and extended up the front wall to the roof. The rammed material was placed about half way up the back wall. A small wood fire was started and gradually increased over 10 hours until the furnace shell was hot, when coke was shoveled in, sufficient being added to form a layer about 6 inches deep.

In about half an hour, this coke was incandescent and the arc was struck. In two hours the furnace was extremely hot, when the current was shut off and the furnace allowed to soak for half an hour. The power again was turned on and the furnace allowed to run for 15 minutes, then shut down for 10 minutes, and this procedure was repeated. After the current had been on for 5 hours, the furnace was ready for steel. This hearth gave fair service, but later was found subject to slight chipping.

A similar hearth was made using sodium silicate as a binder. Excellent results were obtained as long as the furnace could be kept on a moderate production basis, operating at least three heats a day or better, sufficient always to keep the hearth fairly hot. However, as soon as the hearth was allowed to get dead cold, trouble started. The hearth on cooling would tend to crack badly, and later crumble along this line of severance, requiring patching after each shut down, causing much unnecessary labor and delay.

The hearth was removed and one made of a prepared refractory cement and sand used which gave excellent results under any conditions, the cement having the ability to bond strong enough to prohibit any possible crumbling or flaking

TABLE 8

## HEAT LOG OF CARBON STEEL MADE BY TWO SLAG BASIC PROCESS

Railroad wrought scrap comprised the greater portion of the 13,000 pound charge. A total of 8000 pounds of railroad wrought was charged with 5000 pounds of punchings.

The large amount of phosphorus in the wrought iron brought the approximate phosphorus in the charge to 0.100, and as the allowable limit for the product was 0.060 per cent, the required amount to be lowered was slightly over 0.040, there being a slight pick up from the ferromanganese.

The desired specification was:

	Per cent
Carbon .....	0.24 to 0.32
Manganese .....	0.65 to 0.75
Silicon .....	0.24 to 0.32
Phos. and sulphur, under. ....	0.060

The metal was poured into steel castings for locomotive work, the castings requiring a large amount of finishing.

2:10 p. m.

Current on, and drawing as full a load as possible.

2:35

Electrodes digging rather deep. Raised and the holes filled with a small amount of the chage left out of the furnace for this purpose. Beneath this cold scrap was thrown approximately 200 pounds of burned lime.

3:20

Good pool formed in furnace, and a steady load obtained.

4:10

Metal practically all melted, loose pieces poked into bath. About 100 pounds more lime added. The bath is bubbling easily and quite steady. Test slag taken shows a good black in color, and with the desired lava like structure.

4:40

First metal test taken. Shows a dead melt. Carbon judged at 0.120 per cent. Slag of a good color, but slightly thin. 50 pounds additional lime added, and well rabbled into the slag. Given 10 pounds of lump ferrosilicon to quiet the metal.

4:50

Furnace tilted slightly and the slag worked toward the spout. Current off and slag pulled from furnace as quickly as possible.

5:00

Current again on. Ferromanganese figured at 0.50 per cent added. One-half of second slag added from both side doors. This slag made up of burned lime, 350 pounds; gravel spar, 75 pounds; and coke dust 30 pounds, being well mixed on the furnace platform. In 10 minutes the slag was given a good dusting of around coke, and the remainder of this finishing slag added.

5:20

Slag test taken shows a darkish brown, turning to a lighter color in spots. Metal test taken and sent to chemist for manganese and carbon. Doors tightly sealed and furnace allowed to run under a steady load.

5:30

Slag test showing a darkish gray in color. About 25 pounds of finely ground fluorspar was dusted over the slag, with approximately 10 pounds of small sized ferrosilicon. Another dusting of coke and furnace again sealed. The reducing flames are now heavy and luminous. The bath in under perfect reducing conditions.

Chemist reports manganese 0.48, carbon 0.19 per cent.

5:40

Slag showing signs of carbide; powdering in air with a light acetylene odor. Ferromanganese added at 0.10 per cent. Slag foaming slightly under the electrodes.

5:50

Slag a perfect carbide, powdering to a dark gray. Metal test taken still shows slightly wild. Silicon added at 0.05 per cent, with another light dusting of coke. Sample sent to laboratory for final analysis. Metal given a light rabbling and the doors again closed tightly.

6:05

Chemist reports carbon, 0.26 and manganese, 0.68 per cent. Final addition of ferrosilicon figured at 0.80 per cent added and the bath well rabbled.

6:15

Final metal test shows perfectly sound. Ladle called for and metal poured.

Slag after being poured from ladle was cooled in the pit with water and gave off the familiar acetylene odor. Slag analyzed 3.56 per cent calcium carbide.

Final metal analysis.

	Per cent
Carbon . . . . .	0.28
Manganese . . . . .	0.71
Silicon . . . . .	0.30
Phosphorus . . . . .	0.058
Sulphur . . . . .	0.031

Total time for heat 4 hours, 10 minutes. Castings poured perfectly, the metal lying quiet in the molds, and finally shrinking deep in the gates and risers. The metal on machining was easy to cut, and reasonably tough, showing practically no flaws, outside of several small sand spots. A skim gate was used on the furnace, and the metal was poured from a bottom pour ladle, using a two inch nozzle.

TABLE 9

## HEAT LOG OF CARBON STEEL MELT, ONE SLAG BASIC PROCESS

The charge which was made up of 7000 pounds of rail butts and 5500 pounds of borings analyzed approximately carbon, 0.45, manganese, 0.65 and phosphorus and sulphur under 0.045 per cent.

The specification called for carbon, 0.38 to 0.45 per cent with manganese 0.85 to 0.95, phosphorus and sulphur less than 0.050 per cent, and silicon 0.50 to 0.60 per cent. The heat was intended for several large bull gears, those items taking the entire heat.

12:45 a. m.

Current on.

2:00

Furnace under steady load, after having to slip all three electrodes as they dug so low the arms touched the roof glands

2:10

Added about 50 pounds of burned lime

3:00

Added 25 pounds of crushed coke to stop the oxidizing action Metal test taken showed close to 0.35 per cent carbon Metal cold slag thin and black Allowed to heat up

3:20

Tests showed the same conditions as before except the metal was hotter, and the slag had turned to a dark brown Slag mixture totaling 250 pounds of lime and spar added Dusted lightly with coke Took a test for the chemist.

3:35

Test came back carbon 0.37 per cent, manganese 0.59 Added a light touch of coke and about 15 pounds of crushed ferrosilicon, and rabbled the slag well

3:50

Slag assuming carbide conditions, but a little thin Added 30 pounds of lime, rabbling in well, and 10 pounds of ferrosilicon Metal getting hotter

4:00

Slag perfect Metal fracture appears to have picked up about 0.05 per cent carbon. Manganese figured at 0.30 per cent added, together with 0.10 per cent silicon.

4:10

Metal test solid. Slag perfect, and foaming heavily over entire furnace Silicon figured at 0.50 per cent added.

4:30

Heat poured.

The final metal analyzed carbon, 0.44, manganese, 0.91, silicon, 0.57, sulphur, 0.039, phosphorus, 0.047 per cent. The time of heat 3 hours, 45 minutes

TABLE 10

## HEAT LOG OF CARBON STEEL MELT UNDER A WHITE SLAG

The charge of 13,925 pounds of low carbon scrap probably analyzing close to 0.20 per cent carbon, 0.45 per cent manganese, with both phosphorus and sulphur under 0.040 per cent. The major portion of the charge consisted of rather clean boiler plate and punchings. About 200 pounds of burned lime, and 150 pounds of pea sized coke were added between layers of the charge.

The specifications called for the following:

	Per cent
Carbon	0.80 to 0.90
Manganese	0.50 to 0.60
Silicon under	0.15
Phos. and sulphur under	0.040

This metal was not for steel castings, but was to be poured into forging ingots from which track tools were to be made for railroad operations.

2:55 p. m.

Current on.

4:00

Steady load after slipping electrodes, and filling up their holes with fresh scrap.

5:00

Good sized pool formed. Considerable scrap hanging to walls pushed into bath. Slag test shows carbide conditions in spots, but tending to a light brown in others caused by being contaminated with oxide from fresh scrap falling into the metal pool. Gave a light coke dusting.

6:00

All melted. Slag white, but rather thick. Added 50 pounds of gravel fluor-spar, and took metal test for chemist. This test was fairly solid, but too high in carbon for a close reading.

6:20

Test came back 0.62 per cent carbon; manganese 0.42. Added ferromanganese figured at 0.15, and enough flake graphite to bring the carbon up 10 points. This was well rabbled in and the slag given another good coke dusting.

6:50

Perfect conditions Slag a dark gray and powdering in air. Strong acetylene odor on a water quench. Metal fairly sound. Final test taken for analysis. Doors sealed.

7:20

Test analyzed carbon 0.77 and manganese 0.54 per cent. Low phosphorus pig iron added to give five points of carbon. Silicon at 0.20 per cent added in lumps, being slightly moistened before throwing in, in order to splash the slag aside.

7:40

Metal test shows perfectly solid, with the seamed skin showing perfect deoxidation. Slag strongly carbide.

7:45

Heat poured. The metal poured like oil, setting in the molds without a spark.

The final analysis of the metal showed carbon 0.84, manganese 0.52, silicon 0.14, phosphorus 0.040 and sulphur 0.012 per cent.

This slag contained 5.34 per cent calcium carbide. Total time of heat 4 hours 50 minutes. The total current consumption was 5180 kilowatt hours or 740 a ton.

**TABLE 11**  
**OPERATING LOG FOR HARD STEEL**  
**ACID PRACTICE**

The charge consisted of 7900 pounds of miscellaneous plate scrap, covering punchings, and boiler plate, with approximately 80 per cent of rail ends.

Charged with no slag material nor ore.

	Specification	Steel made
Tens. Str.	80,000 lbs.	88,700
Elastic Limit	.45 of ten. st.	47,800
Elongation in 2 inches	15%	18.7%
Reduction of area	20%	40.0%
		Per cent
Carbon . . . . .		0.40
Manganese . . . . .		0.70
Silicon . . . . .		0.87
Sulphur . . . . .		0.047
Phosphorus . . . . .		0.053

2:30

Current on. High side of transformer drawing a load of 1500 to 1600 kilowatts, at about 180 volts.

3:25

Metal all melted, although still rather cold. Slag test shows a dark, grayish black color. Metal test wild, but showing sufficient residual alloys. Carbon judged by fracture to be 0.11 per cent. Sample sent to chemist.

3:30

Finishing slag added, consisting of 8 large scoops of old molding sand, spread as evenly as possible over the bath. Flames immediately turned soft, with heavy clouds of white smoke. Reduction starting.

3:35

Slag thoroughly melted, and due to the long arc, hot and fluid. Test taken shows the first appearance of a dark green color. Metal much hotter. Current thrown over to low side of transformer, drawing about 6000 amps at 110 volts.

3:40

Chemist reports carbon at 0.16 per cent, and manganese at 0.17. Slag test now taken shows a good greenish color, but there is still oxide in the metal, although it sets quietly in the mold, with little sparking. The slag is beginning to thicken slightly, and reduction is proceeding perfectly: 72 pounds of lump, 80 per cent ferromanganese weighed out calculated to 0.72 per cent of the charge. Three large scoops of sand added to the furnace to thicken the slag, and given a light dusting of coke to start heavy reduction. Low phosphorus, low silicon pig iron added in sufficient quantity to bring the carbon up to about 0.45 per cent.

3:45

Slag thick, and a yellowish green in color. Metal free from any oxide. Sample sent for carbon analysis. Silicon now beginning to be reduced into the metal, although not apparent.

3:50

Silicon reducing fast, metal showing silvery in spoon, and setting quickly in mold. Metal rising during solidification. Slag perfect, although thick and tough. Chemist reports carbon at 0.43 per cent.

3:52

Ladle called for and manganese added, being moistened to go through slag.

3:55

Test taken and poured into a sand mold shows perfectly quiet the fracture being of a clear, even grain, with the top of the piece wrinkled, showing perfect solidity. Slag a light yellowish green. Furnace beginning to snow slightly. Heat poured, with no ladle additions.

Power used 2000 kilowatt-hours or about 500 per ton of charge.

Metal held in ladle five minutes, and poured into six castings, this number taking the entire heat.

TABLE 12  
OPERATING LOG FOR SOFT STEEL

## Acid Practice

The charge consisted of 8200 lbs. of miscellaneous low carbon scrap.

	Specification	Steel made
Tens. Str.	60,000 lbs.	69,900
Elas. Lim.	.45 of ten. st.	36,450
Elongation in 2 inches	22%	28.1%
Reduction of area	30%	49.7%
		Per cent
Carbon	.. .. .	0.23
Manganese	.. .. .	0.66
Silicon	.. .. .	0.28
Sulphur	.. .. .	0.044
Phosphorus	.. .. .	0.056

2:45

Current on high side.

3:55

Metal all melted and furnace hot. Changed over to low side after adding 6 large scoops of sand, mixed with one of lime rock in small pieces.

4:00

Metal test taken runs from spoon rather warm, although a light scull is left. Metal shows approximately 0.08 per cent carbon, with low manganese and silicon. 100 pounds of a low phosphorus pig iron added to help clear the metal of oxide and bring up the carbon.

4:05

Slag clearing nicely. Metal getting sounder and hot. Carbon approximately 0.15 per cent. Another ten points of pig added and the slag given a dusting of coke. Reduction heavy, but slag still of a liquid consistency, showing yellowish green, and stringing from the spoon.

4:10

Carbon estimated at 0.25 per cent. Slag temperature O. K.

4:20

Manganese added in lumps to furnace calculated at 0.70 per cent of charge. silicon added in moistened lumps figured at 0.30 per cent of charge.

4:30

Bath well rabbled, and final metal test taken in a sand mold. Every indication satisfactory. Heat tapped. Consumption 2000 kilowatt-hours or about 500 per ton.

Metal held in ladle 5 minutes and poured 20 gages.

## SECOND HEAT

	Specification	Steel made
Tens. Str.	60,000 lbs.	72,200
Elas. Lim.	.45 of ten. st.	39,800
Elongation in 2 inches	22%	27.2%
Reduction of area	30%	41.1%
		Per cent
Carbon	.. .. .	0.25
Manganese	.. .. .	0.64
Silicon	.. .. .	0.31
Sulphur	.. .. .	0.041
Phosphorus	.. .. .	0.058

The charge was 6000 lbs boiler plate scrap.

9:00

Current on.

10:00

Charge melted. Six scoops of old sand added.



10:05

Slag thoroughly melted. Current changed to low side. Metal test shows carbon about 0.12 per cent, metal being in an excellent condition, showing sound around the rim where chilled. Slag, black, with touches of dark green. Still thin.

10:10

Slag thickening as metal heats up. Tests show dark green. Metal about the same. 10 points of carbon added as pig iron.

10:15

Metal runs clear from the spoon. Slag in excellent shape. About 15 pounds of burned lime added to keep slag from getting too thick. Metal test shows satisfactory on the fracture.

10:20

Metal getting hot.

10:26

Manganese figured at 0.65 per cent of charge added to furnace.

10:30

Heat poured, ferrosilicon 0.20 per cent being added to the stream as it runs into the ladle, the alloy being about the size of small peas. Power consumption 2000 kilowatt-hours or about 667 per ton. This heat was poured into 59 slabs, mostly center plates, and buffer castings for car work.

**TABLE 13**  
**OPERATING LOG FOR MEDIUM STEEL**

**Acid Practice**

The charge consisted of 9000 pounds of mixed scrap and 3000 pounds of heads and gates.

	Specification	Steel made
Tens. Str.	70,000 lbs.	79,750
Elastic Limit	.45 of ten. st.	42,200
Elongation in 2 inches	18%	28.4%
Reduction of area	25%	47.7%
		Per cent
Carbon .....		0.35
Manganese .....		0.61
Silicon .....		0.33
Sulphur .....		0.039
Phosphorus .....		0.049

8:00

Current on, high voltage.

9:00

Melting progressing rather fast. Scrap falling into bath struck an electrode, breaking it off at the nipple. Had to be pulled out through the roof with a chain. About 8 inches of the electrode had been dissolved by the metal.

9:30

Current again on, after 30 minutes delay.

10:00

Metal all in. Slag medium, and a dark green color

10:10

Metal test taken, and current thrown over onto low side. The test shows close to 0.30 per cent carbon, with a rather high manganese, and some silicon. Test sent to chemist.

10:20

Carbon 0.32 per cent, with manganese at 0.40. Another metal test taken shows metal warming up slightly, but still full of cold spots, and showing oxide streaks. No silicon reduction apparent at this time

10:30

Slag beginning to reduce, and getting lighter in color. Metal still cold

10:40

Metal hotter, giving a clear run from the spoon. Slag a fine color, but slightly thin. Four scoops of sand added, with an addition of 10 points of carbon, by means of pig iron.

10:45

Silicon beginning to reduce heavily as the temperature of the furnace rises.

10:50

Manganese figured at 0.30 per cent added.

10:55

Final test taken in sand mold, shows excellent conditions. Heat poured.

Power consumed 3750 kilowatt hours or approximately 625 per ton. 12 gates poured on this heat.

TABLE 14

## LOGS OF MANGANESE STEEL HEATS

The charge consisted of the following constituents:

	Pounds
Heads and gates (carbon steel) . . . . .	800
Punchings, low carbon . . . . .	3,000
Turnings . . . . .	650
Ferromanganese (later) . . . . .	780
<b>Total</b> . . . . .	<b>5,230</b>

The analysis of the steel was as follows:

	Per cent
Manganese . . . . .	11.62
Carbon . . . . .	1.28
Silicon . . . . .	.45
Phosphorus . . . . .	.055
Sulphur . . . . .	.011

Total time for heat 4 hours 55 minutes. Kilowatt hour current consumption 8500 or 1835 per ton.

Time

10:20

Power on. Low amperage. Voltage 104 to 106

10:35

Power off to lower electrodes.

10:45

Power on. Amperage 4500.

11:10

3 shovels burned lime, 60 pounds.

1:20

Amperage reduced to 3500, 60 pounds lime added

1:40

All melted.

2:05

First metal test taken, carbon 0.12 per cent. Slag a dark brown.

2:15

25 pounds of ground electrodes added

2:18

Changed to low voltage, 83

2:25

Slag white

2:30

High voltage, 106.

2:32

100 pounds ferromanganese on hearth at each door.

2:40

First 100 pounds in No 1 door, second 100 pounds heating

2:44

First 100 pounds in No. 2 door, second 100 pounds heating.

2:48 to 3:08

Manganese added 100 pounds at a time from alternate doors

3:15

Tapped adding 0.25 per cent silicon to ladle

The weight of metal was 5100 pounds and the weight of the slag was 310 pounds.

The manganese added on this heat figured to 12.00 per cent of the total charge, disregarding that contained in the charge (approximately 0.50 per cent).  
The bend test broke at 135 degrees.

### SECOND HEAT

The charge was constituted as follows:

	Pounds
Heads and gates (carbon steel) . . . . .	500
Punchings . . . . .	4,100
Turnings . . . . .	500
Ferromanganese (later) . . . . .	890
Total . . . . .	5,990

The analysis of the steel was as follows:

	Per cent
Manganese . . . . .	11.02
Carbon . . . . .	1.33
Silicon . . . . .	.56
Phosphorus . . . . .	.046
Sulphur . . . . .	.013

Time of melting 6 hours. Kilowatt hours used 3900 or 1300 per ton.

Time

9:30

Power on. 3000 amperes Voltage, 100 to 102

9:45

75 pounds lime added, 4500 amperes.

11:15

15 pounds lime.

1:00

60 pounds lime.

1:30

First metal tests for carbon, 0.30 to 0.35 on fracture, slag black, to brown in spots.

1:40

Hole in roof.

1:50

60-pound mill scale, 2500 amperes.

2:05

Carbon 0.45 per cent by analysis

2:10

45-pound mill scale

2:15

Carbon 0.30 per cent.

2:20

30-pound mill scale.

2:30

Slagged off.

2:35

100 pounds lime

Up to 3:10

Manganese added

3:20

10-pound ground electrodes.

3:30

Heat tapped, adding 0.40 per cent silicon to ladle.

The weight of the metal was 5655 pounds and the weight of the slag was 350 pounds while the slag was deep green at the pour.

Bend test broke at less than 90 degrees.

The two logs here given were made from two heats melted under poor conditions in a new shop where the practice had not been thoroughly developed. Consequently they can be classed only as mediocre heats.

To show what a difference practice makes, the logs shown in Table 15. Appendix, are given from heats made one year later

TABLE 15  
LOGS OF MANGANESE STEEL HEATS

The first charge was made up as follows:

	Pounds
Boiler plate scrap . . . . .	3,000
Clean turnings . . . . .	3,000
Ferromanganese (later) . . . . .	1,150
Total . . . . .	7,150

The analysis of the steel was as follows:

	Per cent
Manganese . . . . .	12.69
Carbon . . . . .	1.15
Silicon . . . . .	.33
Phosphorus . . . . .	.066
Sulphur . . . . .	.008

Time for heat, 4 hours 15 minutes, Kilowatt hours current consumption was 3000 or 840 per ton.

8:00

Current on at 120 volts and 4500 amperes.

After a light pool was formed 100 pounds of burned lime was added to form a melting down slag.

10:00

All melted. Test taken shows a dead melt. Carbon later analyzed 0.06 per cent Raked walls clean.

10:15

Bath given a good dusting of ground coke, and second slag added. This slag was made of 200 pounds burned lime, 75 pounds fluorspar, and 25 pounds, powdered coke, thoroughly mixed before adding

10:30

Slag well rabbled and given another heavy coke dusting.

10:40

Slag brown, and porous Reduction proceeding rapidly

10:50

40 pounds gravel spar added, and more coke. Metal heating up

11:00

Metal hot. Slag beginning to powder in air Metal test shows approximately 0.12 per cent carbon, fairly sound 20 pounds of ferrosilicon added.

Manganese placed on door sills 100 pounds added every 2 minutes from alternate door sills

11:30

Manganese in all furnace Metal medium Slag green Added 50 pounds lime and gave a good dusting of coke Metal test taken, quenched, and bent shows about 90 degrees before failure, with touches of color on fracture Structure crystalline.

11:50

Slag white, and slightly powdering in places No carbide conditions. Metal test bent 120 degrees, but still shows color Structure tending to silky.

Added 25 pounds lime, and another dusting of coke. Sealed furnace as tightly as possible, and threw current on to its highest possible load

12:00

Slag whitish green in spots, powdering in others Fairly thick and working slightly under the electrodes.

Metal test bent over 150 degrees Fracture absolutely clear of any color, and showing a silvery white. Silky. Added ferrosilicon figured to 0.25 per cent.

12:10

Metal perfect. Slag powdering with a greenish yellow color.

12:15

Poured.

The final bend tests on this heat went flat on themselves without fracture.

## SECOND HEAT

The charge included 7000 pounds of plate scrap and 1850 pounds of ferro-manganese giving a total of 8850 pounds.

The analysis of the steel was as follows:

	Per cent
Manganese	12.72
Carbon	1.20
Silicon	.41
Phosphorus	.072
Sulphur	.010

Time of heat 4 hours 30 minutes. Kilowatt hour current consumption was 3500 or 839 per ton.

12:00

Current on at maximum load.

As soon as pool formed added 75 pounds lime.

2:10

Metal melted. Metal test about 0.10 per cent carbon.

2:30

Finishing slag added; 250 pounds lime, 75 pounds fluorspar, and 35 pounds ground coke.

2:45

Slag well rabbled and given heavy dusting of coke. Slag brown in spots. Furnace well sealed.

3:00

Slag light brown. Added 25 pound spar.

3:15

Slag white and powdering. Metal fairly hot.

Manganese weighed out and added 100 pounds at a time.

3:45

Manganese all in. Slag greenish blue.

Gave heavy dusting of coke, and 40 pounds lime.

4:00

Slag a light greenish white. Metal bends 120 degrees with very little color.

Another dusting of coke and furnace sealed.

4:15

Furnace snowing. Slag white. Metal perfect and hot.

Silicon figured at 0.35 per cent added. Furnace sealed.

4:30

Metal in proper condition and sufficiently hot.

Heat poured.

Bend tests, 180 degrees without any checks appearing

TABLE 16

## HEAT LOGS OF MANGANESE STEEL USING SHOP SCRAP

## Twenty-five Per Cent Alloyed Shop Scrap

The charge was made up as follows:

	Pounds
Punchings, low carbon	4800
Turnings, clean	540
Shop returns	1200
Ferromanganese	889
<b>Total</b>	<b>6929</b>

The total poured was 6750 pounds, melting loss 2.5 per cent, time of heat, 3 hours and 45 minutes, and the current consumption was 725 kilowatt-hours per ton.

The analysis of metal was as follows:

	Per cent
Manganese	12.89
Carbon	1.02
Silicon	0.37
Phosphorus	0.063
Sulphur	0.010

The test bar bent 180 degrees without checking.

8:00 a. m.

Current on.

8:30

Electrodes raised, 200 pounds lime thrown in holes, and covered with fresh scrap.

10:30

Heat melted. Slag, a dark greenish brown. Fairly thin. Melt down carbon approximately 0.25 per cent. Slag given 25 lbs. of crushed ferrosilicon covered with 75 pounds of burned lime.

10:40

Metal getting hotter. Slag now a greyish brown. Given 25 pounds lime, and a heavy dusting of coke. Furnace sealed.

11:00

Slag a greenish white. Added 50 pounds lime and 20 pounds fluorspar. Another heavy dusting of coke. Furnace again sealed.

11:20

Slag light green, heavily basic. Manganese added.

11:30

Manganese all in furnace. Metal well rabbled. 25 pounds fluorspar added, and another heavy coke dusting. Slag a pea green.

11:35

Metal Test shows bend of about 120 degrees without any trace of color on fracture. Metal hot. Slag a light green.

11:45

Metal perfect. Slag a greenish white, powdering slightly to a yellowish green powder. Heat poured.

This heat came down under perfect conditions, requiring little manipulation before being ready to pour.

## Second Heat Containing 25 Per Cent of Alloyed Shop Scrap

The charge was made as follows:

	Pounds
Punchings	4000
Turnings	500
Shop scrap	1500
Ferromanganese	872
<b>Total</b>	<b>6872</b>

## Analysis of steel:

	Per cent
Manganese .....	11.48
Carbon .....	1.06
Silicon .....	0.61
Phosphorus .....	0.080
Sulphur .....	0.014

The total poured 6700 pounds with a melting loss of 2.5 per cent. The time of the heat was 3 hours and 30 minutes and kilowatt-hours per ton current consumption was 876. The bend test started checking at 140 degrees.

1:00 p. m.

Current on. 150 pounds lime added after a good sized pool had formed.

2:50

Heat all melted, but cold.

3:10

First metal test taken. Shows approximately 0.30 per cent carbon Slag a medium green, with black patches. Gave a good dusting with gas coke, and added 150 pounds of lime mixed with 50 pounds spar. Gave another good heavy coke dusting, and sealed the furnace.

3:45

Heat fairly hot. Slag white and powdering Consistency good. Began adding manganese.

4:00

Manganese all in. Slag a blue green. Gave 50 pounds lime, and dusted with 10 pounds finely crushed ferrosilicon. Gave a medium dusting of coke, and sealed furnace.

4:15

Metal test satisfactory. Slag light green Temperature too low. Threw current at highest figure.

4:25

Metal in perfect pouring condition, and hot Slag blue green. Added ferrosilicon at 0.35 per cent in lumps.

4:30

Poured heat.

## Fifty Per Cent Alloyed Shop Returns

The charge was rattled free of scale and was made up as follows:

	Pounds
Punchings .....	2500
Turnings .....	484
Shop metal .....	2984
Ferromanganese .....	680
Total .....	6598

## Analysis of metal:

	Per cent
Manganese .....	13.23
Carbon .....	1.30
Silicon .....	0.44
Phosphorus .....	0.079
Sulphur .....	0.007

The total poured was 6180 pounds, melting loss, 2.5 per cent and the bend test gave 180 degrees. The time of the heat was 3 hours and 30 minutes and the current consumption 812 kilowatt-hours per ton.

10:00

Current on. 50 pounds lime added as soon as first pool formed.

12:00

Heat all melted. Gave a dusting of coke, and added 200 pounds lime. Sealed furnace.



12:20

Slag blue. Metal appeared good, but was too high in manganese for any fracture estimate. Added 50 pounds lime and gave a very heavy coke dusting.

1:00

Metal getting rather hot. Slag a light blue Heat coming down fine. Began adding manganese.

1:15

Manganese all in. Metal getting extremely hot Metal test bends 90 degrees, but showing color Added 25 pounds of lump ferrosilicon, dusted with coke, added 50 pounds lime and sealed furnace

1:30

Metal test satisfactory. Slag a blue green Metal hot Poured heat

#### Eighty Per Cent Alloyed Shop Returns

The charge was rattled until absolutely free of scale, and shiny It contained the following:

60 lb manganese ore on hearth

	Pounds
Punchings	1000
Turnings	178
Shop metal	4665
Ferromanganese	321
Total	6167

Analysis of metal

	Per cent
Manganese	12.11
Carbon	1.33
Silicon	0.50
Phosphorus	0.081
Sulphur	0.010

The total poured was 6010 pounds, melting loss 2.5 per cent. The bend test gave 140 degrees. Time of heat was 5 hours, 25 minutes and the current consumption was 833 kilowatt-hours per ton

8:00 a. m.

Current on As soon as pool had formed added 150 pounds of lime

11:00

Heat all melted Test taken and sent to chemist Fracture on this test heavily colored with little bend before breaking Slag green Added 30 pounds of petroleum coke and 50 pounds lime The coke started a heavy churning action causing good circulation of the slag Doors sealed

11:30

Chemist reports manganese, 8.88 per cent and carbon 0.93 per cent in metal Slag approximately 20.0 per cent manganese. Slag a blue green Gave a heavy dusting of coke mixed with lime and again sealed doors Metal test taken here shows a little bend, but contains less color.

12:00

Slag same green color Metal heating up a little Began adding manganese in 100-pound lot Cut down current.

12:15

Manganese all in Added 50 pounds lime, gave heavy coke dusting and sealed doors.

12:30

Test taken bends about 45 degrees, showing color Sent to chemist for analysis.

1:00

Chemist reports manganese, 12.01 per cent, with carbon at 1.26 per cent Bend test went 100 degrees with no color, although fracture was coarsely crystalline.

1:15

Bend test went over 120 degrees, showing a soft silky texture on fracture. Slag light green. Ferrosilicon added at 0.40 per cent. Furnace given an other good coke dusting and ladle called for

1:25

Heat poured.

TABLE 17  
FURNACE LOG ON HEAT OF NICKEL STEEL

Acid Operation

The specification sought was: Carbon, 0.26 to 0.32 per cent; nickel, 1.90 to 2.10 per cent, with other alloys standard.

The analysis of the steel made was as follows: Carbon, 0.23 per cent; nickel, 1.98 per cent; manganese, 0.60 per cent; silicon, 0.30 per cent.

Charge

Boiler plate, heavy . . . . .	3000 lbs.
Ingot butts . . . . .	3000 lbs.
Total . . . . .	6000 lbs.

Sufficient pig nickel was added on the hearth to bring the metal to 2.00 per cent, calculated on weight of the charge.

The time for heat was 1 hour, 35 minutes with a current consumption of 600 kilowatt-hours per ton. Twenty-nine castings were poured.

9:00 a. m.

Current on at 180 volts. Load being drawn at this figure, 1800 kilowatts.

9:20

Current off for two minutes to lower electrodes.

9:45

Metal melting rapidly, and large sized pool formed. Bar thrust into slag for test shows a dark green, rather thin. Flame from around electrodes yellowish white, with brown oxide vapors. Raked banks as clean as possible.

10:00

Metal all melted. Added five large scoops of old floor sand, evenly spread over the bath.

10:05

Current thrown over to low tap on furnace. Metal test taken shows rather low carbon, according to the bend before breaking. Sample sent to chemist. The slag has thoroughly melted, being of a medium green in color, still containing oxides, as can be seen by its fluidity. The metal is still rather cold, a small skull remaining in the spoon.

10:10

Metal getting hotter, but still skulking the spoon. Test on fracture shows no change over the first one. Slag bubbling in furnace, and getting lighter in color, although still fluid.

10:15

Metal pours clean from the test spoon, and has the clear, silvery color denoting freedom from any large amount of oxide. Slag a light green, beginning to get thicker and tending to string from the spoon.

10:20

Chemist reports carbon at 0.14 per cent, and manganese at 0.32 per cent. Metal is now hot, and pours from the spoon in a clear, silvery stream. Slag perfect, yellowish green, puffing in the air, and stringing from the spoon. Added wash metal to raise the carbon 0.10 per cent. Three large scoops of sand added to thicken the slag and start the silicon to reducing. The bath given a light dusting of crushed coke.

10:25

Metal hot, and silicon coming down fast. Slag thick and gummy, of a light yellowish color having a slight greenish tinge. Metal test broken shows the familiar silicon blow. Silicon estimated at 0.10 in the test. Smoke from around the electrode holders is a dense white, with luminous flames denoting perfect conditions of reduction. The furnace is beginning to snow slightly as can be noticed by the electrodes where they enter the roof becoming blue gray.

10:30

Metal test estimated not less than 0.15 per cent silicon, probably nearer 0.20 per

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cent. Wash metal at 0.05 per cent carbon, and ferromanganese at 0.40 per cent manganese, added to the furnace both being slightly moistened to break through the slag. Rod set, and ladle called.

10:35

Metal test poured into a dry sand mold, shows absolute solidity, having the familiar wrinkled surface of a thoroughly deoxidized steel.

Heat poured, 0.05 per cent of wheat size ferrosilicon being added to the ladle during the first part of the stream. Metal held in ladle for ten minutes before first casting was poured. Size of nozzle brick used, 2 inches

TABLE 18  
FURNACE LOG ON HEAT OF NICKEL STEEL

Acid Operation on Shop Returns

The specification sought was: Carbon, 0.22 to 0.26 per cent; nickel, 3.25 to 3.75 per cent; other alloys standard.

The analysis of the steel made was: Carbon, 0.24 per cent, nickel, 3.53 per cent; manganese, 0.57 per cent, silicon, 0.29 per cent.

Charge

Nickel steel shop scrap with an average analysis of 2.00 per cent nickel...7500 lbs.

Pig nickel added with the charge to bring the analysis of the charge to 3.50 per cent nickel.

The time of the heat was 1 hour, 25 minutes. It was made on a hot furnace with a current consumption of 585 kilowatt-hours per ton. Fourteen castings were poured.

2:00 p. m.

Current on high side of transformer. Small amount of coke required under No. 2 electrode to furnish good conduction at the start, some of the sand on the scrap holding back contact.

2:50

Heat all melted. Slag test shows a medium green, and a little too thick. 50 pounds lump iron ore added.

2:55

Ore foaming slag. Part of slag drawn off and a metal test taken, which shows a higher silicon than desired. 40 lbs burned lime added to slag to thin it enough to prevent any further silicon increase. Test sent to chemist for carbon.

3:00

Ore has finished working, and silicon pickup has been overcome. The slag has gone back to a darker green, and is fluid. The metal is heating up, but the test spoon still shows a light skull. The metal still contains oxide as can be seen from the reddish brown spots on its surface when taken from the furnace. The bath given a light coke dusting. Flame coming from around the electrodes luminous and of a soft yellow in color, accompanied by dense white fumes.

3:05

Chemist reports carbon at 0.19 per cent, and manganese at 0.42 per cent. Silicon estimated at 0.10 per cent. The metal has thrown off its oxide, being of a silvery appearance when poured, pouring clean from the spoon. The slag is of a light green yellow in color, and is just beginning to thicken. Current thrown on to low tap.

3:10

Metal hot. Slag of a perfect color, and bubbling on the metal. Test taken strings from the spoon, and bright flames given off from the slag as withdrawn from the furnace. Metal test shows no change from first fracture. Slag thickened with silica sand, and small piece of pig added to start reduction of silicon. Flames from around electrodes have died down, but the small amount coming from the furnace are a luminous yellow, accompanied by a thin whitish yellow smoke.

3:15

Metal hot. Slag thick and gummy, but of a perfect color. Silicon estimated in test at about 0.20 per cent. Slag foaming under the arc, and giving off bright blue flames.

3:20

Ferromanganese figured at 0.30 added, together with wash metal calculated to raise the carbon 7 points.

3:25

Silicon calculated at least 0.25 per cent, the metal test giving absolute solidity in a dry sand test mold. The metal is hot, giving off sharp blue flames as poured from the spoon, with a surface which is mirror like in its freedom from oxide. The test bar has the familiar silicon shrink accompanied with wrinkles along the rim.

Heat poured, the metal held in the ladle 12 minutes. Size of nozzle used on this heat:  $1\frac{1}{4}$  inches.

TABLE 19  
LOG OF NICKEL STEEL HEAT

## Basic Operation

The specification sought was: Carbon, 0.30 to 0.35 per cent; nickel, 3.25 to 3.75 per cent; other alloys standard.

The steel analyzed: Carbon, 0.32 per cent; nickel, 3.44 per cent; manganese, 0.61 per cent; silicon, 0.30 per cent; sulphur, 0.024 per cent; phosphorus, 0.041 per cent.

## Charge

Nickel steel scrap . . . . .	10,500 lbs.
(Av. 2.00% Ni.)	
Low phos. punchings . . . . .	3,500 lbs.
Total . . . . .	14,000 lbs.

The time of the heat was 3 hours, 45 minutes with a current consumption of 660 kilowatt-hours per ton. Forty-two castings were poured.

7:45 a. m.

Current on.

As electrodes dig near the hearth they are raised and fresh scrap thrown in. A small amount of lime was added, just sufficient to form enough of a slag body to hold a steady load.

9:30

Charge about three-quarters melted. Slag given a good heavy dusting of pulverized anthracite coal followed by 200 pounds of lime.

10:20

Charge all melted and metal medium. Slag is of a medium brown in color. 75 pounds lime added and another good dusting of coke given.

10:40

Metal hot. Current cut down. Slag a whitish brown and thick. 50 pounds fluorspar added and rabbled in. Metal test sent to chemist. Ferrosilicon at 0.20 per cent added. Dusting of coke and doors sealed.

11:00

Metal hot, and thoroughly solid on fracture cast in chill mold. Slag perfect, foaming, and powdering gray, with strong carbide composition. Chemist reports on previous test carbon at 0.27 per cent, and manganese at 0.45 per cent. Ferromanganese at 0.20 per cent added. Pig nickel added to bring total charge up to 3.50 per cent. Ferrosilicon at 0.15 per cent added. Slag coked and furnace sealed.

11:20

Metal solid in sand mold, hot, and perfect in appearance. Slag excellent.

11:30

Furnace tapped, using skim gate. 15 pounds spar to ladle. Metal held in ladle ten minutes before pouring. Poured perfectly sound.

TABLE 20  
LOG OF NICKEL STEEL HEAT

## Basic Operation

The specification sought was: Carbon, 0.22 to 0.26 per cent; nickel, 1.85 to 2.15 per cent, other alloys standard.

The steel made analyzed: Carbon, 0.23 per cent; nickel, 2.04 per cent; manganese, 0.65 per cent; silicon, 0.31 per cent; sulphur, 0.015 per cent; phosphorus, 0.031 per cent.

## Charge

Punchings	..	..	..	..	..	..	7,000 lbs.
Boiler plate	.....	.	.	..	.	.	7,000 lbs.
Total	.	.	.	..	.	.....	14,000 lbs.

The time of heat was 4 hours, 20 minutes with a current consumption of 750 kilowatt-hours per ton. Twelve gates were poured.

4:08 p. m.

Current on, 8000 amperes at 110 volts.

4:22 to 4:50

Electrodes raised as they dig through the scrap, and fresh metal charged in the holes, covering the first slag which consists of three per cent of the charge, burned lime.

5:10

Current off for three minutes to pull out stub of broken electrode.

6:05

Bath well melted. 25 pounds lump iron ore added.

6:50

Charge all melted, and fairly hot. Metal test taken and judged at 0.08 per cent carbon by fracture. Slag dead black, but thin. 50 pounds burned lime added, and rabbled through the slag to thicken preparatory to removing the dephosphorizing slag.

7:05

Current off and the greater part of the slag removed with wooden tipped rabble bars.

7:10

Current again on. The bare metal was given a heavy dusting of ground coke; followed by one-half of the final slag consisting of 3 per cent of the charge lime, well mixed with 50 pounds of gravel fluorspar. Covered with a good coating of coke. Ferromanganese at 0.60 per cent manganese added, together with sufficient shot nickel to bring the analysis to 2.00 per cent nickel. Furnace sealed.

7:35

Metal test taken. Slag powders to a light gray. Metal rather hot. Sample sent to chemist. 15 pounds ferro-silicon added in lumps, and another heavy dusting of coke added.

7:55

Slag perfect, foaming heavily, powdering to a dark gray, and giving off a strong acetylene odor when water cooled. Chemist reports carbon at 0.18 per cent and manganese at 0.57 per cent. Metal test taken shows hot metal, but still slightly gassy. Ferrosilicon at 0.25 per cent added, together with wash metal at 0.05 per cent. 25 pounds lime added and the slag again dusted with coke. All furnace openings have sealed themselves with silicon soot.

8:20

Metal test taken and poured into a sand mold shows perfect soundness and solidity when fractured, with the familiar silicon dip of the surface, so common to thoroughly sound basic steel. Slag strongly carbide, and powdering dark gray. Metal is hot.

8:28

Heat tapped, 15 pounds of finely ground fluorspar being added to the stream as it runs from the ladle. When ladle is nearly full, and slag begins running, 8 scoops of lime added to thicken slag on top of ladle. Ladle covered well with fine coke to prevent any oxidation from the cold air.

Metal poured beautifully from a 2-inch nozzle into some rather large ship castings.

TABLE 21

## FURNACE LOG ON HEAT OF CHROME STEEL

## Acid Operation

Steel castings intended for use as the jaws in rock crushers. The analysis sought was: Carbon, 0.90 to 1.00 per cent; chromium, 1.00 to 1.10 per cent. The steel analyzed when finished as follows: Carbon, 0.92 per cent; manganese, 0.58 per cent; silicon, 0.24 per cent; chromium, 1.13 per cent. The charge consisted of 6200 pounds of old coiled springs. The time of heat was 1 hour, 20 minutes, and the current consumption was 560 kilowatt-hours per ton.

2:40 p. m.

Current on at high voltage. Three scoops of molding sand added to hearth, together with 25 pounds of anthracite coal.

3:30

Charge melted, and fairly hot. Slag has come down as a clear green, but rather thin. Five large scoops of dry silica sand added. The metal test on fracture shows a high carbon, too high to judge with any accuracy. Test shows fairly solid. Sample sent to laboratory.

3:35

The slag has thoroughly diffused over the bath, and is hot. Current cut to low voltage.

3:40

Chemist reports carbon at 0.81 per cent. Wash metal added at 0.20 per cent carbon. Slag given light dusting of coke. Furnace scaled.

3:50

Metal extremely hot. Slag perfect, being a yellowish green and tough and stringy. Fracture test shows good solidity.

3:55

Ferromanganese at 0.50 per cent manganese, and ferrochrome at 1.25 per cent added.

Bath given a good rabbling.

4:00

Current off and heat poured. Ferrosilicon at 0.10 per cent silicon in wheat size added to ladle.

## Acid Operation

Heat for castings for cutter blades with a desired content of carbon, 0.40 to 0.50 per cent, and chromium, 0.45 to 0.60 per cent. The finished steel analyzed: Carbon, 0.45 per cent; chromium, 0.53 per cent; silicon, 0.33 per cent; manganese, 0.65 per cent. The charge consisted of 8000 pounds mixed scrap, with about 25 per cent shop returns. The time of heat was 1 hour, 40 minutes, and the current consumption 575 kilowatt-hours per ton.

2:10 p. m.

Current on.

3:15

Heat melted. Fracture shows approximately 0.15 per cent carbon. Slag thin and black. Six large scoops of old molding sand added, with 100 pounds low phosphorus pig iron.

3:20

Current thrown on to low side. Slag well mixed, with dark green color. Metal still full of oxide, and skulls spoon.

3:25

Slag clearing, metal getting hotter. Carbon fracture estimated at 0.25 per cent carbon. 100 pounds pig added.

3:30

Metal pours hotter, but still slightly skulls the spoon. Slag light green. Two large scoops silica sand added. Fracture estimated at about 0.33 per cent carbon.

3:40

Metal hot, pours clear from the spoon. Slag perfect with slight tendency to thicken. Twenty pounds crushed limestone added over slag. Metal test estimated at 0.35 per cent carbon. Wash metal added to bring to 0.50 per cent.

3:45

All conditions perfect. Silicon starting to come up slightly. Manganese and chrome added. Current thrown on to high side to thin the slag for pouring

3:50

Heat tapped.

#### Basic Operation

The specification called for carbon, 0.60 to 0.70 per cent and chromium, 0.90 to 1.10 per cent. The steel made an analysis as follows: Carbon, 0.67 per cent; chrome, 1.02 per cent; silicon, 0.26 per cent; manganese, 0.55 per cent; sulphur, 0.016 per cent; phosphorus, 0.038 per cent. The charge was 15,000 pounds of chrome scrap averaging 0.55 per cent chromium. The time of the heat was 3 hours, 55 minutes and the current used was 600 kilowatt-hours per ton

#### Heat Made On Hot Furnace

2:40 p m

Current on The scrap was clean 75 pounds of crushed limestone added in center of charge.

4:15

Charge about half melted, large pool of metal in center Fifty pounds crushed coke added, together with 100 pounds of burned lime Furnace tightly sealed Conditions reducing as can be seen by the soft, luminous flame coming from around electrodes

5:10

Charge all melted. Walls raked clean Slag a light brown. Metal cold Dusted heavily with ground coke and added 100 pounds lime, and 40 pounds spar Doors tightly sealed.

5:40

Slag white and powdering in the air Metal getting hot Fracture judged at 0.50 per cent carbon. Sample sent to chemist for analysis Given a dusting of coke and the doors sealed

6:00

Chemist reports carbon at 0.52 per cent; manganese at 0.46 per cent; and chromium at 0.48 per cent Ferromanganese ferrochrome, and wash metal added in proper amount Silicon at 0.15 per cent added and furnace closed

6:20

Metal hot, and sound on fracture Slag perfect Foaming in furnace, powdering gray in air, and giving off heavy odors of acetylene when water quenched Silicon at 0.15 per cent added

6:35

Heat tapped

#### Basic Operation

The specification called for carbon, 0.40 to 0.50 per cent and chrome, 0.50 to 0.60 per cent, while the steel made ran as follows: Carbon, 0.43 per cent, chromium 0.58 per cent, manganese, 0.71 per cent; silicon, 0.30 per cent, sulphur, 0.020 per cent, phosphorus, 0.031 per cent The charge consisted of 13,000 pounds mixed basic open hearth scrap The time of the heat was 3 hours, 15 minutes and the current 615 kilowatt-hours per ton

11:00 a m

Current on 250 pounds lime added with charge

1:00 p m

All melted. Fracture shows dead melt Slag black and thin Fifty pounds lime added to thicken slag.

1:20

Slag raked and poured off Ferromanganese added. Finishing slag added, 250 pounds lime, 50 pounds spar, and 50 pounds crushed coke. Furnace sealed.

1:50

Slag powdering and of a good carbide character Metal pours clean from the spoon. Low phosphorus pig added to bring up carbon Ferrochrome added and ferrosilicon at one-half of total required Given good coke dusting

2:10

Metal sound, slag perfect All conditions ready for pouring. Balance of silicon added.

2:15

Heat tapped.



TABLE 22  
HEAT LOG OF HIGH SILICON STEEL

## Acid Furnace Practice

Steel, intended for large sugar mill driving gears was made to the following analysis: Carbon, 0.30 to 0.35 per cent, manganese, 0.65 to 0.70 per cent, silicon, 0.50 to 0.70 per cent. The resulting metal analyzed: Carbon, 0.34 per cent, manganese, 0.71 per cent, silicon, 0.66 per cent

The charge consisted of 7200 pounds of soft steel scrap and 50 pounds crushed coke added on hearth

The time of the heat was 1 hour 25 minutes, made on a hot hearth, and the current consumption 585 kilowatt hours per ton. Four gates were poured through a 1½-inch nozzle.

1:30 p. m.

Current on at highest possible voltage, 180 volts at 4500 amperes

No slag making materials added

2:20

Heat melted and walls raked clean. Little slag on the steel, what is in furnace is a greenish black. Metal rather cold, but shows approximately 0.30 per cent carbon, the coke having effectively done its work in holding this element in check. Six large scoops of old, dry floor sand carefully spread over the surface of the bath.

2:25

This sand has thoroughly diffused, and the slag is extremely hot, due to the long arc. Current thrown over to low voltage, about 110 volts. Metal is heating, but still contains considerable free oxide.

2:30

Slag a medium green in color, but still rather thin and containing quite an amount of oxide. Metal still skull in the spoon. Carbon constant by fracture.

2:35

Slag fast turning lighter in color. Metal test practically free of oxide, and left slight skull in spoon. Slag thickened with 3 large scoops of sand, and given a dusting of coke to throw down silicon.

2:40

Slag perfect, yellowish green thick and viscous stringing from the spoon, and foaming when the door is opened. As withdrawn, the slag puffs up and the gases burn with sharp blue, pointed flames. Metal pours clean from the spoon, shows no trace of oxide, but the silicon has not yet started to reduce.

2:45

All conditions perfect. Silicon coming down fast, the metal beginning to show wildness due to the escape of oxygen from the reduced silica, the blow holes having the silvery color associated with this reaction. Silicon estimated at 0.10 per cent, no drop in carbon being shown. Carbon raised 0.10 per cent by addition of pig iron.

2:50

Metal extremely hot, pouring from the spoon in a silvery stream, and settling in the chill mold at once, but rising badly due to the escape of occluded oxygen. The silicon now estimated at about 0.20 per cent, with the carbon at about 0.32 per cent. Slag a light yellowish green, rather thick and stringy. Ferro-manganese at 0.60 per cent, manganese and ferrosilicon at 0.60 per cent silicon added, both being moistened and added in lumps.

2:55

Heat tapped, the slag being raked from the pouring door with a hook as the heat is tapped. Steel extremely quiet in ladle and in the molds.

Metal held in the ladle ten minutes before the first mold was poured. Almost the entire heat was poured into one large crown wheel, the remainder being poured into three small cut gears. On machining the metal cut easily, with no trace of hardness or tendency toward brittle metal.

TABLE 23

## HEAT LOG OF HIGH SILICON STEEL.

## Basic Furnace Practice

The specification called for: Carbon, 0.24 to 0.32 per cent; silicon, 0.45 to 0.60 per cent; manganese, 0.60 to 0.70 per cent. The steel as made analyzed as follows: Carbon 0.27 per cent; silicon, 0.56 per cent; manganese, 0.62 per cent.

The charge consisted of 14,175 pounds of miscellaneous foundry scrap. The time of heat was 8 hours, 50 minutes and the kilowatt hour per ton current consumption was 538.

12:00 p. m.

Current on.

12:30

Electrodes raised one at a time, and lime added, being covered with fresh scrap. Approximately 75 pounds lime added in this manner.

2:00 a. m.

Charge all melted, walls scraped. Fifty pounds of crushed coke added, mixed with 250 pounds of burned lime. Doors sealed.

2:35

Slag rather thick. Fifty pounds fluorspar added and thoroughly rabbled into the slag. The slag is a medium brown in color. Metal is fairly hot. Current cut slightly.

3:00

Slag white and powdering. No carbide character. Metal hot. Fracture estimated at 0.20 per cent carbon. Ferromanganese at 0.40 per cent added. Given a heavy dusting of coke and the doors sealed.

3:20

Slag strongly carbide, powdering dark gray. Metal hot, and fairly sound. Ferro-silicon added at 0.70 per cent silicon.

3:40

Metal thoroughly sound and hot. Slag perfect, foaming over entire surface of

3:50

Heat tapped.

TABLE 24  
LOG OF ACID ELECTRIC FURNACE IRON

## Soft Machineable Iron

The specification called for soft iron capable of being machined at high speeds and to take a high polish. The iron made analyzed: Total carbon, 3.64 per cent; silicon, 2.48 per cent; manganese, 0.57 per cent; sulphur, 0.075 per cent.

The charge consisted of cast iron borings, 4500 pounds; shop returns, 5000 pounds; outside scrap, 2500 pounds; ferrosilicon, 120 pounds; ferromanganese, 36 pounds; gas coke, 120 pounds.

The time for the heat was 2 hours, 45 minutes. A 6-ton heroult furnace was used and the current used was 510 kilowatt-hours per ton, using a hot furnace immediately following a heat of steel.

8:10 a. m.

Current on. Pulling good load from the start.

9:10

Charge rapidly melting. Added 50 pounds pen size anthracite coal.

10:00

Practically all molten Test taken in sand mold.

10:15

Metal heating, but still skulking the spoon. Previous test broken. Metal shows a soft fracture Six large scoops of sand mixed with 3 of burned lime added.

10:25

Slag well rabbled Metal getting hot. Fracture thoroughly solid in chill mold.

10:35

Slag thoroughly mixed, very glassy and of a whitish gray color. Slag test poured in chill mold shows solid fracture with no evidence of shot or gas pockets.

10:45

Ferrosilicon and ferromanganese added. The slag given a dusting of coke

10:50

Metal extremely hot All appearances good.

10:55

Heat tapped Castings poured perfectly the metal being extremely hot and easily pouring the most intricate pieces Heat was poured on the floor for 45 minutes, the ladles draining perfectly clean No pugged metal.

## HARD IRON

The specification called for hard gray, no machining, but must be capable of being drilled, to be used for retorts for sugar refining work. The iron made analyzed: Total carbon, 3.05 per cent; silicon, 2.25 per cent; manganese, 0.27 per cent; phosphorus, 0.31 per cent; sulphur, 0.061 per cent.

The charge consisted of steel borings, 3000 pounds; shop returns, 3000 pounds; ferrosilicon, 135 pounds; and low ash coke, 210 pounds.

The time for the heat was 1 hour, 10 minutes with 490 kilowatt hours per ton current consumption.

2:00

Current on. The coke was added with the charge as was the ferrosilicon.

2:45

Charge completely melted. Metal test taken and poured into chill mold to estimate carbon. Another test poured in sand mold for softness. Four scoops of sand mixed with lime added. Furnace given a light dusting of coke dust.

3:00

Previous softness test shows satisfactory. Chill test had previously been estimated at over 3 per cent Slag fairly good, but rather lumpy. Given a good rabbling, and 20 pounds fluorspar added.

3:05

Slag a light yellow, and glassy. Good covering on metal.

3:10

Heat poured. Metal extremely hot. Sample bar poured on heat machined medium; drilled readily. Fracture of gates rather close grained, and considerably tougher than the average gate poured from the cupola.

TABLE 25

## HEAT LOG OF A HEAT OF DUPLEXED GRAY IRON

The metal from cupola analyzed: Total carbon, 3.41 per cent; silicon, 1.37 per cent; manganese, 0.49 per cent; phosphorus, 0.62 per cent; sulphur, 0.129 per cent.

The charge in the cupola consisted of 20 per cent steel scrap, 40 per cent shop return and 40 per cent cast scrap. The metal from electric furnace analyzed: Total carbon, 3.29 per cent; silicon, 2.34 per cent; manganese, 0.44 per cent, phosphorus, 0.63 per cent; sulphur, 0.027 per cent. The time for heat was 2 hours 10 minutes with 267 kilowatt hours per ton current consumption; 18,085 pounds of metal was poured from electric furnace.

10:00 a. m.

Furnace started on approximately 10,000 pounds of metal from cupola. As the iron was poured into the furnace, 400 pounds of the following slag mixture was added: Lime 60 per cent, fluorspar 20 per cent, and crushed coke 20 per cent. Given a heavy covering of crushed petroleum coke, and the doors sealed. Power on at heaviest load

10:50

Furnace given a kicker of about 8000 pounds of cupola iron. Doors again sealed.

11:10

Slag thoroughly rabbled and 50 pounds of spar added. Metal test taken and sent to chemist. At this point the metal is medium in temperature, the first ladle of cupola iron having been rather cold.

11:20

The slag has been a heavy carbide one right from the start, but at this point it has gone over into a perfect molten, and fairly thin condition. It shows excellent reduction. The metal pours nicely, with a distinct dip in the mold.

11:30

Ferroalloys added and well rabbled into the metal.

11:40

Test taken shows good diffusion of the silicon. The metal is hot, and the slag perfect.

12:00

Metal ready to pour, but held up 10 minutes waiting for the ladle.

12:10

Furnace tapped. Metal was poured from large crane ladle into smaller ones for pouring, considerable shanking being done. No skulls at finish. All machined work.

TABLE 26

## HEAT LOG OF COLP GRAY IRON

The specification called for the softest quality of iron for high speed cutting. The iron analyzed: Carbon, 2.63 per cent; manganese, 0.54 per cent; silicon, 2.37 per cent; phosphorus, 0.43 per cent; sulphur, 0.013 per cent. The charge consisted of 14,000 pounds of cast iron scrap containing an average of 0.10 per cent sulphur. The time for the heat was 3 hours, while the current consumption was 570 kilowatt hours per ton.

6:30 a. m.

Current on. 400 pounds of lime-spar slag added with the charge together with 100 pounds, low ash coke, ground to wheat size.

7:00

Current off to lower an electrode. Load steady, and iron melting down fast.

8:30

Charge all melted, walls raked clean. Slag rabbled and small amount of coke added.

8:40

Metal test taken. Metal rather old. Slag a dark gray, powdering strongly carbide.

9:00

Previous metal test broken. The iron is a soft gray, giving every evidence of extreme softness. Small amount of manganese added to tighten the grain. Metal now medium. All conditions O. K.

9:05

Slag given a rabbling and 50 pounds fluor spar added. Small dusting of coke made.

9:10

Metal test taken. Metal hot. Slag perfect.

9:25

Previous metal test broken. Metal satisfactory.

9:30

Heat poured

This heat was shanked from a bottom pour ladle. The metal as it poured into the molds was bluish and emitting sharp white flames. The heads dipped deeply showing perfect solidification and fluidity. The appearance of the castings was perfect, and when machined they showed considerably better in regard to small spots than a similar iron made in the cupola.

TABLE 27

## LOGS ON HEATS MADE FROM IRON BORINGS

## FIRST HEAT

The charge at the start consisted of 500 pounds of shell rings, 2400 pounds of borings, 100 pounds coke and 25 pounds of lime.

The current was on at 8:05 a. m. Rabbled banks at 8:30, 8:55, 9:30 and 10:15 a. m. Bath was ready at 10:30 for remainder of the charge. Additional borings totaling 1600 pounds charged.

10:50

Carbide slag put on.

11:00

70 pounds 50 per cent ferrosilicon added

11:15

Heat poured.

Total time for heat: 3 hours, 10 minutes. Total charge 4570 pounds. Kilowatt hours per ton, 569.

Note: 500 pounds of metal was left in the furnace for the second heat instead of charging shell rings. If carbide slag had been allowed to act longer the silicon content would probably have been a little higher. The analysis of the iron showed. Total carbon, 3.49 per cent; graphitic carbon, 2.89 per cent; silicon, 2.20 per cent.

On this heat a thin plate about  $\frac{3}{4}$ -inch section, 12 x 18 inches ribbed on the under side with  $\frac{3}{4}$  x  $\frac{3}{4}$ -inch ribs and having a large number of  $\frac{1}{4}$ -inch holes on 1-inch centers in both directions was poured. Also a can was poured weighing about 25 pounds and with a section  $\frac{3}{4}$ -inch thick. These castings were broken to show the fracture and were then taken to the machine shop, where they were filed, chipped and hammered, and the working qualities pronounced perfect.

## SECOND HEAT

The metal left in furnace totaled about 500 pounds. To this 4580 pounds of borings, 150 pounds of coke and 30 pounds of lime were added. A part of the borings, 100 pounds, was charged then the coke and lime, and then about 500 pounds more of borings. The remainder of the charge was added in two lots as the charge melted down. The heat was rabbled several times to clean the walls.

11:40 a. m.

Current on

2:35 p. m.

Carbide slag put on.

2:50

75 pounds ferrosilicon added

3:20

Heat poured.

Total time, 3 hours 50 minutes.

Kilowatt hours per ton, 524.

The analysis of metal showed a total carbon of 3.52 per cent; graphitic carbon, 2.77 per cent; and silicon, 2.61 per cent. Melting loss on both of the two heats was 2.76 per cent. Electrode consumption, 10 pounds of graphite electrodes per ton. The heats were made in a 3-ton Ludlum basic lined furnace for a test on its applicability for gray iron.

## Heat Made in a 6-ton Heroult Furnace

The charge consisted of 15,500 pounds of cast iron borings.

5:30 p. m.

Current on. From this time until 7:00 the remainder of the charge was shoveled into the furnace as fast as possible.

7:00

As soon as melted the walls were scraped clean of hanging metal, and the remainder of this scrap shoved into the center of the furnace under the electrodes.

8:00

Metal nearly all melted. Test taken for chemist, and walls finally cleaned.

8:10

150 pounds lime, 50 pounds spar, and 100 pounds ground coke added, well mixed.

8:25

Lowered current.

8:40

Chemist reports manganese, 0.60 per cent; silicon estimated at about 1.80 per cent. As silicon was desired at about 2.25 per cent, and manganese at 0.80 to 1.00 per cent, these alloys were added.

8:55

Heat poured.

The final analysis showed total carbon, 3.80 per cent; manganese, 0.91 per cent; silicon, 2.18 per cent; phosphorus, 0.42 per cent; sulphur, 0.041 per cent. Time for heat: 3 hours, 25 minutes. Kilowatt hours per ton, 520.

TABLE 28

## HEAT LOG OF ALLOYED WHITE IRON

The charge consisted of 4000 pounds of clean borings and turnings, analyzing approximately: carbon 0.80 per cent, manganese, 0.50 per cent; silicon, 0.04 per cent. The analysis desired was: Carbon 3.00 to 3.50 per cent; manganese 0.70 to 0.90 per cent, silicon, 0.70 to 0.90 per cent. A radical structure was sought.

The final analysis of iron was: Carbon, 3.54 per cent; manganese, 0.87 per cent, silicon, 0.79 per cent, chromium, 0.65 per cent, phosphorus, 0.061 per cent; sulphur, 0.023 per cent.

About 1000 pounds of borings was charged on the hearth, followed by 240 pounds of 4 mesh coke, and a ground mixture containing 80 pounds lime and 20 pounds fluorspar. The remainder of the metal was charged and the doors sealed with a heavy clay mud.

8:00 a. m.

Current on. Contact poor at the start, and the load drawn by the furnace was low

8:30

Load picking up as metal melts and forms better contact. Black fumes are emitted from around the electrode cooling rings due to the large amount of coke present.

8:45

Load steady, due to the metal having formed a good slag covered pool. The slag is holding the arc from surging.

9:30

Scrap has been going in fast, as told by the manner in which the furnace has been growing, and the height to which the electrodes have raised. Dense reducing flames coming up around the electrodes

9:40

Door opened and a small amount of scrap hanging on the banks shoved in. Slag test coming from the furnace on the poke bar gives a heavy acetylene odor reducing when water quenched into a dark green powder. Slag a little heavy, and 20 pounds fluorspar added together with 2 shovels of anthracite coal.

9:45

Heat all melted. Metal test taken and poured into a sand mold, on end. Metal fairly hot, running clean from the spoon. Slag still too cold to foam, furnace again sealed

10:00

Previous metal test now is black in the mold. Water cooled and broken, fracture estimated at close to 3.25 per cent carbon, the crystalline structure being well defined, but blow holes are prevalent around the rim of the test. Sent to chemist for carbon check. Another metal and slag test taken, the metal is hot and pours clean from the spoon. Slag strongly carbide, powdering dark gray and medium fluid. Given 20 pounds spai and 2 shovels anthracite coal. Vigorously boiled for 5 minutes with green wood poles

10:20

Chemist reports carbon at 3.32 per cent and manganese at 0.30 per cent. Second metal test taken now broken and shows carbon approximately 10 points higher, with no evidence of gas pockets. Structure assuming distinct radial appearance; 23 pounds ferromanganese and 36 pounds of ferrosilicon added.

10:30

36 pounds ferrosilicon and 53 pounds of ferrochromium added. Both given a heavy rabbling.

10:35

Metal test taken. Temperature high, metal giving off sharp blue flames when poured from the spoon, and having the blue appearance of hot steel. Slag foaming slightly and heavy in its carbide character

10:45

Final metal test shows a distinct star fracture, the crystal being clearly defined, of fairly large size, with a dead, steel gray color, having absolutely no trace of



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gas holes or poroussness. Top of test bar has the wrinkled appearance of absolute freedom of any dissolved or included gas.

Heat tapped. Metal held in ladle 10 minutes before pouring the first mold.

The total time for heat was 2 hours, 45 minutes and the current consumption was 640 kilowatt-hours per ton of charge.

Test balls broke on 55, 52 and 58 blows.

Brinell hardness number was 432.



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